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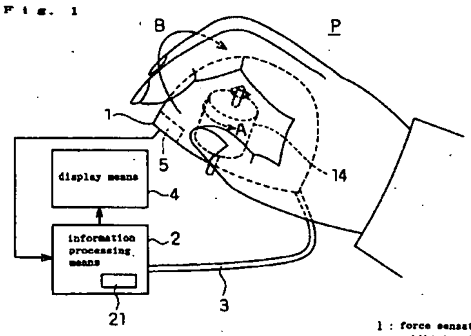
(54) Force-feedback data input device.

(57) A force sensation exhibiting device has a housing which can be grasped by a hand, at least one rotatably or linearly movable motor contained in the housing , an input section where repulsive force informations are input, and control circuit for driving and controlling said motor according to the repulsive force informations, wherein a force sensation is given to said hand by a drive of the motor.

Fig. 1



1 : force sensation exhibiting device

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DETAILED DESCRIPTION OF THE INVENTION

Field of the Invention

The present invention relates to a force sensation exhibiting device, a data input device and a data input equipment which are applicable to the one which makes an operator feel as if a virtual object as a data within a calculator is actually present, to make a modeling operation done in the computer and to experience preliminarily how to use the product without manufacturing a prototype, or the one in which the operator can operate the object in a remote area while feeling as if it is in hand.

Related Art

Fig. 13 is a view showing the structure of a conventional simulator by means of an input method by fingers and an image display device. This is to experience preliminarily how to use by operating an object which does not actually exist by fingers. The operator 120 is equipped with a system glove 110 for inputting informations so that the machine can read the positional data of the fingers. As the system glove 110 for inputting the informations, there can be mentioned a data glove of V.P.L. Research Co. in U.S.A. (hereinafter referred to as "VPL Co."). The data glove of VPL Co. is to detect the bending angle of the fingers by sewing an optical fiber on an usual thin glove to utilize the change of the light transmittance of the optical fiber by the bending of the optical fiber caused by bending the fingers. The thus obtained mechanical positional data of the fingers is sent to the contacting force-sensing type calculating means 112 in the information processing means 2. The contacting force-sensing type calculating means 112 calculates the shape data 115 of the virtual object and the input positions of the fingers input to calculate the positional relations between the fingers and the object. For example, when the fingers are on the surface or in minutely inner side than the surface of the virtual object, it is when the fingers touch the virtual object. And when there are more than two faces to be touched, it is possible to operate to lift the virtual object. Thus obtained positional relations of the virtual object and the hand and fingers are displayed as an image by the display means 4 via the image-forming means 113, which can let the operator 120 know the positional relations of his fingers and the virtual object. Thus, it is realized that the operator 120 operates the virtual object by his fingers.

Such a position detecting method by the optical fibers can provide the wide range of positional informations of the fingers, since it does not restrict the movement of the fingers and the arm of the operator 120. Furthermore, the positions and postures of palm can be detected by a position/posture sensor mounted to the glove 110. As a position/posture sensor, there can be mentioned what uses a magnetism or what uses an ultrasonic wave. Furthermore, in case of a remote manipulation, it can be applied by operating not the virtual object but the actual object through the display means 4.

In such a conventional device, however, when operating the virtual object by detecting the positional informations of the fingers, the operator has to confirm the positional relations of his fingers to the virtual object through the display means 4, and he cannot use the force sensation which is generally used when the human being operates objects. Therefore, it has been difficult for the operator to feel as if the virtual object exists and he is operating it.

On the other hand, as a means for exhibiting the force sensation, there have been proposed a method which provides a master manipulator having a shape corresponding to the fingers to the operator to control the manipulator by force, (such as "artificial reality corresponding to the force sensation - development of a multi-dimensional force sensation feedback device" by Iwata, et al, at 5th Human Interface Symposium, 1989). Sato, et al has proposed a method to give the force sensation by the tension of a thread, by stringing threads in space and operating the intersection points of the threads ("Interface device - SPIDAR - for the virtual working space" by Sato, et al, Shingaku Giho, PRU-88, 1989). However, either of them has a problem that the device becomes big.

Furthermore, it is possible to add a force sensation feedback mechanism on the data glove of VPL Co., or to realize a force sensation feedback by mounting and controlling a motor with a position detector to the fingers. But it is usable only when the glove or the mechanism portion is attached. Therefore, it has a problem that when using it, it requires time to attach and detach the glove or the mechanism portion.

SUMMARY OF THE INVENTION

Considering these foregoing problems of conventional various devices, the present invention provides an easily operable three-dimensional data input equipment which gives a repulsive force to the whole hand and also gives a bending angle of the hand and fingers and force sensation by a force sensation exhibiting device for fingers not to be mounted, or provides an equipment which can move the position of the whole hand in a wide range of three-dimensional space.

The first aspect of the present invention (corresponding to claim 1) is a housing which can be grasped by hand, wherein at least one of a rotatable motor or a linearly movable motor is contained.

The second aspect of the present invention (corresponding to claims 2 and 3) drives intermittently a motor corresponding to a force vector to be given so that the torque is proportional to the magnitude of said vector, and in the intermittent drive, the period of turning off the motor is longer than the period until said activated motor stops.

The third aspect of the present invention (corresponding to claim 4) provides a control means which repeats activating motion, moving in the reverse direction, and stopping motion, in which a motor corresponding to said vector is activated so that the torque is proportional to the magnitude of said vector, and after being moved in a certain distance or a certain angle, activated in an extremely low torque in the direction reverse to that of the former activation, and when returns to the position or the angle before said activation is initiated, said motor is stopped.

The 4th aspect of the present invention (corresponding to claim 5) provides a pressure detecting means on the surface of the housing with which the fingers contact to detect the pressure from the fingers.

The 5th aspect of the present invention (corresponding to claim 7) comprises a data input device according to the fourth aspect of the present invention, an information processing means for processing the input data, and an image display means, said image display means being equipped with a means for displaying the positions, postures and bending states of at least two fingers as the information corresponding to said data input device.

The 6th aspect of the present invention (corresponding to claim 8) provides a pressure detecting means and a repulsive force generating means for generating a pressure in the direction reverse to the detected pressure on the surface of the housing with which the fingers contact.

The 7th aspect of the present invention (corresponding to claim 13) provides a means for controlling a repulsive force generating means so that the pressure of the pressure detecting means becomes equal to the objective repulsive force.

The 8th aspect of the present invention (corresponding to claim 14) comprises a force sensation exhibiting device, an image display means and a calculation means for calculating the force sensation value for exhibition, said image display means being equipped with a means for displaying the positions, postures and bending states of at least two fingers as the informations corresponding to said force sensation exhibiting means.

The 9th aspect of the present invention (corresponding to claims 15, 16 and 17) provides an auxiliary input means composed of a means for detecting a force of plural axes.

The 10th aspect of the present invention (corresponding to claims 18 and 19) provides a section of an auxiliary input means and force sensation exhibiting device or a data input device on the same housing to operate the two input means by the right and left hands.

The 11th aspect of the present invention (corresponding to claim 20) provides a force sensation exhibiting device for hands or a data input device for hands on the one end of the arm portion and a polyaxes force sensor on the other end of the arm portion, to make an input to the polyaxes force sensor section by the overall operation of the force sensation exhibiting device section for hands or the data input device section for hands.

The 12th aspect of the present invention (corresponding to claim 21) makes the shape of the device section grasped by hand substantially cylindrical.

The 13th aspect of the present invention (corresponding to claim 22) is mounted with a device for hands at the tip of a manipulator having multi degrees of freedom to give a repulsive force to the tip by a means for controlling the manipulator as well as by using a force applied to the manipulator as an auxiliary input.

The 14th aspect of the present invention (corresponding to claim 23) provides a barrel shaped leaf spring in which the portion pushed by fingers corresponds to the central portion of the arc to control the radius of the leaf spring.

The 15th aspect of the present invention (corresponding to claim 24) comprises a means for oscillatingly changing the radius of the barrel shaped leaf spring, said oscillating wave form being a wave form which repeats changing abruptly in the direction of increasing the radius, and changing moderately in the reverse direction, or the reverse action.

The 16th aspect of the present invention (corresponding to claim 25) provides a switch operable by fingers not participating in the grasp, which makes it possible to stop temporarily the input of the change of bending of fingers.

The 17th aspect of the present invention (corresponding to claim 26) provides a switch operable by fingers not participating in the grasp, which makes it possible to stop temporarily the input of the informations of overall positions or postures of fingers.

The 18th aspect of the present invention (corresponding to claims 27 and 28) provides a switch operable by hand not grasping or an auxiliary input

means, which makes it possible to stop temporarily the input of the change of bending of fingers or the informations of overall positions or postures of fingers.

The 19th aspect of the present invention (corresponding to claims 29 and 30) controls bending of fingers in a remote area or virtual fingers based on the integral value or incomplete integral value of the detected force.

The 20th aspect of the present invention (corresponding to claims 31 and 32) controls bending of fingers in a remote area or virtual fingers based on a value substantially holding the maximum value of the detected force.

The 21st aspect of the present invention (corresponding to claims 33 and 34) comprises detecting means for detecting a displacement or a pressure at each section with which belly portions of a finger between each joint of fingers contacts at the time of grasping to input data such as bending of each joint of fingers.

The 22nd aspect of the present invention (corresponding to claims 35, 36, 37 and 38) provides a means for adjusting the size of a diameter of substantially cylindrical shape.

The 23rd aspect of the present invention (corresponding to claim 39) comprises a means for detecting a movement or a force of each finger in the left or the right direction, which makes the detected value as being the difference between the detecting values of two detecting means provided for each direction of the two directions.

The 24th aspect of the present invention (corresponding to claim 40) provides a low-pass filter against the detected displacement or pressure and uses a value passed through the filter.

The 25th aspect of the present invention (corresponding to claims 41 and 42) provides a means for calculating a dead zone which regards as there is no input when the detected displacement or pressure is below a certain value, and uses a value passed through said signal processing means.

The 26th aspect of the present invention (corresponding to claims 43, 44 and 45) subtracts the resulting value of the detecting means for detecting a displacement or a pressure which is the minimum but not zero, or the sum of the resulting values of all detecting means which detect displacements or pressures below a certain value, or the sum of the resulting value of detecting means which detect displacements or pressures below a certain value obtained from the maximum displacement or pressure, from the respective detected resulting values of the displacement or pressure which is given from the contacts with the belly portions of fingers between each joint of fingers at the time of grasping, and makes the value the input data.

The 27th aspect of the present invention (corresponding to claim 46) identifies in advance the interrelationship between the detected resulting value of the displacement or pressure which is given from the contacts with the belly portions of fingers between each joint of fingers at the time of grasping and the intention to bend the fingers of the person who grasps it, by using a neural network in which the detecting result is to be an input and the intention is to be an output, inputs the detected results to the identified neural network, and takes out the bending informations of fingers as an output to use it as an input.

The 28th aspect of the present invention (corresponding to claim 47) provides an ultrasonic vibration motor comprising a piezoelectric ceramics and an elastic body which generates a force in the same face with the belly portion of fingers in the portion with which the belly portion between each joint of fingers contacts at the time of grasping, and provides a means for detecting a displacement or a pressure in the vertical direction against the face of the belly portion of fingers at the lower part of said ultrasonic vibration motor.

The 29th aspect of the present invention (corresponding to claim 48 and 49) comprises a reciprocal converting means for detecting a displacement or a pressure in the vertical direction against the face of the belly portion of fingers to determine the reciprocal, and a means for determining a product of the objective value of the force to be given within the face of the belly portion of fingers and said reciprocal converting means, and drives the ultrasonic vibration motor in proportion to the product.

The 30th aspect of the present invention (corresponding to claim 50) provides an ultrasonic vibration motor comprising a piezoelectric ceramics and an elastic body which generates a force in the same face with the belly portion of fingers, in the portion with which the belly portion between each joint of fingers contacts at the time of grasping, and makes an average current of the ultrasonic vibration motor to be the magnitude of the force within the contact face of said belly portion of fingers.

According to the first and second aspects of the present invention, a repulsive force can be given to the grasping hand when the motor in the housing is activated. While the motor is off in the intermittent drive, a reverse and weak repulsive force is generated, but it is not sensed by the human hand. And when the motor is activated again, the repulsive force can be obtained and the repulsive force in the rotating direction is held to be given to the whole hand.

Furthermore, according to the third aspect of the present invention, by reversing the motor during the corresponding period to the OFF period

according to the second aspect of the present invention, it becomes possible for the movable portion to return to the center of the movable range even in the motor of a linear motion type, whereby the repulsive force of the linear motion is held to be given to the whole hand, without the movable portion coming to the dead end over the movable range.

According to the 4th aspect of the present invention, by detecting the strength of the pressure of the palm side of fingers, the bending degree of fingers for grasping a virtual object can be determined according to the strength by utilizing a force close to the intention of the operator.

According to the 5th aspect of the present invention, by using the input device of the fourth aspect of the present invention, the intention to bend the fingers given to the input device is displayed on the display means as a bending of the actual fingers, thereby it becomes possible to grasp or pick up the object within the display screen by utilizing the strength of the force to bend the fingers.

According to the 6th aspect of the present invention, it becomes possible to sense the repulsive force from the virtual object in the fingers by the repulsive force generating means.

According to the 7th aspect of the present invention, by detecting the pressure of the palm side of fingers and controlling the repulsive force generating means so as to become a pressure to be exhibited, a repulsive force when grasping a virtual object by bending the fingers can be obtained freely.

According to the 8th aspect of the present invention, while the positions and angles of fingers are displayed on the display means, the repulsive force is fed back to the fingers, thereby a complex work such as deforming the virtual object becomes possible.

According to the 9th aspect of the present invention, by using a force input in the auxiliary input means, the position and the posture of the hand in the calculator can be changed in a wide range without accompanying a large shift of a force sensation exhibiting device grasped by hand.

According to the 10th aspect of the present invention, by providing an auxiliary input means and a force sensation exhibiting device section for hands or a data input device portion for hands on the common housing and operating them by both hands, the operator can use his one hand to hold the input device housing alternately.

According to the 11th aspect of the present invention, a force input can be given to the polyaxes force sensor portion by operating the force sensation exhibiting device portion for hands or the data input device portion for hands by the whole one hand, thereby a wide range of positional data input by one hand and a minute positional data input by the palm can be made possible.

According to the 12th aspect of the present invention, by making the shape of the portion to be grasped cylindrical, the contact area at the palm portion other than fingers can be enlarged and the operator can support the device by the palm to make it easy to input the force informations of each finger.

According to the 13th aspect of the present invention, a repulsive force can be generated to the whole wrist by the means for controlling the manipulator.

According to the 14th aspect of the present invention, by enlarging the radius of the barrel shaped leaf spring, the rigidity of the leaf spring in the direction pushed by fingers decreases, and by making the radius small, the rigidity can be increased.

According to the 15th aspect of the present invention, by changing the rigidity oscillatingly, when the rigidity increases, the fingers feel as if fingers are pushed back, and when the rigidity decreases, fingers feel as if they are pulled in. But due to the nonlinearity of the human sense, only the part of the rapid change can be sensed, therefore the sensation to be pushed back or the sensation to be pulled in can be generated continuously.

According to the 16th, 17th and 18th aspects of the present invention, by a switch operated by a finger not participating in the grasp, or a switch operated by a hand not participating in the grasp, the bending informations of fingers or positions/postures informations of fingers are fixed.

According to the 19th and 20th aspects of the present invention, since the force by fingers are held by an integral means or a maximum value-holding means, the grasp of a virtual object or an object in a remote area can be continued, without exerting a big force continuously.

According to the 21st aspect of the present invention, the intention corresponding to the bending of each joint of fingers can be detected by a detecting means corresponding to the bending of each joint.

According to the 22nd aspect of the present invention, by enlarging the size of a diameter of substantially cylindrical shape, it is possible to make the shape easy to grasp for the people having large hands, and by making the diameter small, it is possible to make the shape easy to grasp for the people with small hands.

According to the 23rd aspect of the present invention, by determining the difference of the detected results of the right and left sides, it can be possible to obtain the same detected results when fingers are small, and therefore a force or displace-

ment cannot be detected from the two detecting means, and when fingers are large, and therefore a force or displacement can be detected simultaneously from the two detecting means.

According to the 24th aspect of the present invention, fine changes such as trembles of fingers and unevenness of the force can be removed by a low-pass filter.

According to the 25th aspect of the present invention, a faint force not related to the intention are removed by a means for calculating a dead zone.

According to the 26th aspect of the present invention, since the force not related to the intention, but related to holding of the device is relatively small, the influences of the force can be removed, and only the informations relating to the intention to bend the fingers are taken out.

According to the 27th aspect of the present invention, since the force relations between the intention to bend the fingers and the force to hold the device is identified preliminarily as a neural network, the informations of the intention to bend the fingers can be taken out as an output by inputting the detected results to the neural network.

According to the 28th and 29th aspects of the present invention, it becomes possible to generate a force in the direction of the inner surface of the fingers by an ultrasonic vibration motor, and even if the force to push vertically against the surface of a finger is changed, the change is detected, and when the pushing force is weak, the magnitude of the force can be changed to correct the weakness, thereby a force along the objective value can always be generated.

According to the 30th aspect of the present invention, since the electric current of the ultrasonic vibration motor corresponds to the magnitude of the load, the load can be detected by the current, and the force given by the fingers in the inner face direction of the belly of the finger can be detected.

Brief Description of Drawings

Fig. 1 is a perspective view showing the relation between the force sensation exhibiting device and the information processing means in one embodiment of the present invention.

Fig. 2 is a circuit block diagram exhibiting a force sensation in the rotating direction in one embodiment of the present invention.

Fig. 3 is a signal waveform diagram of the force sensation exhibiting circuit in the rotating direction in one embodiment of the present invention.

Fig. 4 is a circuit block diagram exhibiting a force sensation in the linear direction in one embodiment of the present invention.

Fig. 5 is a signal waveform diagram of the force sensation exhibiting circuit in the linear direction in one embodiment of the present invention.

Fig. 6 is a structural perspective view of the data input device in one embodiment of the present invention.

Fig. 7 is a sectional view of the data input device in one embodiment of the present invention.

Fig. 8 is a perspective view showing the using condition of the data input device in one embodiment of the present invention.

Fig. 9 is a structural sectional view of the repulsive force generating mechanism of fingers in one embodiment of the present invention.

Fig. 10 is a circuit block diagram for controlling a repulsive force in one embodiment of the present invention.

Fig. 11 is a perspective view showing the relations with the auxiliary input means in one embodiment of the present invention.

Fig. 12 is a perspective view showing the relations with other auxiliary means in one embodiment of the present invention.

Fig. 13 is a block diagram showing a structural example of the conventional data input equipment.

Fig. 14 is a perspective view showing the state holding a cylindrical device.

Fig. 15 is a perspective view showing the state holding a spherical device.

Fig. 16 is a perspective view showing a contact portion of the device shape with the palm.

Fig. 17 is a perspective view showing the relation with a manipulator in one embodiment of the present invention.

Fig. 18 is a structural sectional view of a compliance control means in one embodiment of the present invention.

Fig. 19 is a waveform of a control signal of the repulsive force sensation in one embodiment of the present invention.

Fig. 20 is a waveform of a control signal of the repulsive force sensation in one embodiment of the present invention.

Fig. 21 is a perspective view showing the state holding a device in one embodiment of the present invention.

Fig. 22 is a perspective view showing an operational example of one embodiment of the present invention.

Fig. 23 is a perspective view showing the state operating the device in one embodiment of the present invention.

Fig. 24 is a signal processing circuit diagram in one embodiment of the present invention.

Fig. 25 is a waveform diagram showing one embodiment of the operation signal in Fig. 24.

Fig. 26 is a signal processing circuit diagram in one embodiment of the present invention.

Fig. 27 is a waveform diagram showing one embodiment of the operation signal in Fig. 26.

Fig. 28 is a perspective view showing the arrangement examples of the detecting means of a cylindrical device in one embodiment of the present invention.

Fig. 29 is a perspective view showing one embodiment of the diameter adjusting means of a cylindrical device in one embodiment of the present invention.

Fig. 30 is a sectional view showing the relation between the finger and the detector in one embodiment of the present invention.

Fig. 31 is a characteristic waveform diagram showing one example of the detected results in Fig. 30.

Fig. 32 is a signal processing circuit diagram in one embodiment of the present invention.

Fig. 33 is a signal processing circuit diagram in one embodiment of the present invention.

Fig. 34 is a perspective view showing the state of holding a cylindrical device in one embodiment of the present invention.

Fig. 35 is a view showing the relation with a force vector in a cylindrical device in one embodiment of the present invention.

Fig. 36 is a signal processing circuit diagram in one embodiment of the present invention.

Fig. 37 is a signal processing circuit diagram in one embodiment of the present invention.

Fig. 38 is a signal processing circuit diagram in one embodiment of the present invention.

Fig. 39 is a signal processing circuit diagram in one embodiment of the present invention.

Fig. 40 is a circuit block diagram showing a structural example of a neural network in the signal processing circuit of one embodiment of the present invention.

Fig. 41 is a structural block diagram showing the operational principle of the ultrasonic vibration motor in one embodiment of the present invention.

Fig. 42 is a view of operational shapes showing the operational principle of the ultrasonic vibration motor in one embodiment of the present invention.

Fig. 43 is an enlarged view of the operational shapes showing the operational principle of the ultrasonic vibration motor in one embodiment of the present invention.

Fig. 44 is a structural sectional view and a signal processing circuit diagram in one embodiment of the present invention.

Preferred embodiments

The embodiments of the present invention will now be described in detail with reference to the accompanying drawings.

Fig. 1 is a view showing the relations between the force sensation exhibiting device, the information processing means and the display means in one embodiment of the present invention. The force sensation exhibiting device 1 is connected to the information processing means 2 via a cable 3. The informations relating to the exhibition of the force sensation are displayed on the display means as image informations. The operator can easily know the cause why the force sensation is obtained, by seeing the display screen. Incidentally, the information processing means 2 can know at any time the informations about the position of the force sensation exhibiting device 1 in the three-dimensional space, as a position-detecting means 5 is mounted, for example, on the force sensation exhibiting device 1. In the memory 21 of the information processing means 2, adequate informations of the repulsive force respectively corresponding to various positional informations are housed in advance in the form of a table. For example, in the case that a hand comes to the place P where the hand hits against the wall, a repulsive force is caused, and in the place other than P, the repulsive force is to be 0. When the operator moves the force sensation exhibiting device 1, the position-detecting means 5 detects the position, the information thereof is input to the information processing means 2, and the table in the memory 21 is referred to calculate if it is necessary to give a repulsive force or not by the information processing means 2, and the necessary informations of a repulsive force is transmitted from the information processing means 2 to the force sensation exhibiting device 1. The force sensation exhibiting device 1 generates a repulsive force based on the repulsive force informations by means of a built-in repulsive force generating means 14. The principle which becomes the basis of the generation of the repulsive force uses the acceleration by means of a motor 14 disposed in the inside of the force sensation exhibiting device 1. That is, by a rotation of the motor in the direction shown by an arrow A, a hand receives a repulsive force in the direction shown by an arrow B. The embodiments according to the first, second and third aspects of the present invention will now be described with reference to the drawings in the order of Figs. 2, 3, 4 and 5.

Fig. 2 is a block diagram illustrating the circuit for exhibiting the force sensation in the rotation direction, and Fig. 3 is a signal waveform diagram showing the principle of the control operation. The necessary force sensation informations determined at the information processing means 2 are input to the drive control means 11. The drive control means 11 inputs an instruction signal to a drive circuit 12 and a switch circuit 13 of the motor 14.

Since the drive circuit 12 is connected to the motor 14 via a switch circuit 13, the ON/OFF operation of the motor becomes possible. Next, the method of drive control and the principles of operations are described with reference to Fig. 3. The signal (a) of Fig. 3 shows the necessary repulsive force informations output from the information processing means 2. That is, it is assumed that the instruction of a "large" repulsive force is output from the time t1 to t2, and the instruction of a "no" repulsive force is output from the time t2 to t3, and the instruction of a "small" repulsive force is output from the time t3 to t4. The signal (b) is an output signal waveform of the drive control means 11. The drive control means 11 drives the motor intermittently responsive to the instruction of a "large" repulsive force. The drive level during ON is a large drive level corresponding to the repulsive force. The time width during the ON pulse is set to be a time width in which the motor can be activated and the velocity is in an accelerated state. The time width during the OFF pulse is set to be longer than the time when the activated motor 14 stops. On the other hand, in the case of "no" repulsive force, the drive control means 11 keeps its drive instruction of the motor 14 OFF. Furthermore, in the case of "small" repulsive force, the drive control means 11 drives intermittently by a not so large ON pulse. Fig. 3 (c) shows the velocity response of the motor 14 responsive to the drive instruction of (b). When the ON pulse is applied, the motor 14 is activated, and the velocity increases rapidly. Since the ON pulse is made OFF while the velocity is unsaturated, the velocity of the motor 14 begins to decrease and stops soon. When the repulsive force is large, the increase of the velocity at the time of activation is fast, and when the repulsive force is small, the increase of the velocity at the time of activation is relatively slow. Fig. 3 (d) shows the acceleration response of the motor 14. When the ON pulse is applied, a relatively large acceleration is obtained in the positive direction, and a relatively small acceleration is obtained during the OFF period until being stopped. Furthermore, there is a difference in the magnitude of the acceleration depending on the magnitude of the ON pulse. On the other hand, when a certain object is held, if the object causes an acceleration in order to start a motion, the person who is holding the object gets a repulsive force which is equal to the product of the acceleration and the mass of the object. Therefore, when the acceleration shown in Fig. 3 (d) is caused, the operator can feel a repulsive force in the direction reverse to that shown in Fig. 3 (d). Furthermore, human sense has a nonlinearity, and a detection limit which hardly senses a small stimulus, therefore the acceleration during the OFF period cannot be detected. Accordingly, the acceleration sensed during the ON period can be sensed as a repulsive force.

Figs. 4 and 5 are signal waveform diagrams showing the circuit structure and the principles of the control operations in the case where the repulsive force is caused similarly as in the rotation direction with respect to the repulsive force in the linear direction. In the case of the shift in the linear direction, the shift range is limited, and a repulsive force cannot be generated continuously in the same control method as that of the rotation direction. Referring to Fig. 4, the repulsive force informations output by the information processing means 2 is input to the profile converting means 21. The profile converting means 21 outputs a position control instruction corresponding to the repulsive force informations. The position control instruction is input to the position control circuit comprising a comparator circuit 22, a drive circuit 23, a linear motor 26, a position detector 25, and a position detecting circuit 24, whereby the linear motor 26 is operated as the position control instructions. Fig. 5 is a signal waveform diagram showing the control operation of the circuits shown in Fig. 4. The waveform (e) shows a waveform of the position instruction signal by the profile converting means 21 with respect to the objective repulsive force (a). The profile converting means 21 outputs an instruction to return gradually to the original position after shifting abruptly, when it is necessary to generate a repulsive force. The shift volume when shifting abruptly corresponds to the magnitude of the required repulsive force. The waveform (f) shows a velocity of the linear motor 26 with respect to the position instruction. Similarly, the waveform (g) shows the acceleration. In the waveform (g), a relatively large acceleration is obtained intermittenly, and a small acceleration is obtained except for the above case. The larger acceleration can be detected by the operator, and the smaller acceleration is below the limit which can be detected by the operator. Therefore, the operator can sense a repulsive force only in the direction which requires a repulsive force.

As described with reference to Figs. 2, 3, 4 and 5, a repulsive force sensation can be given in the rotation direction and in the linear direction with respect to the force sensation exhibiting device 1. Incidentally, though not described in the above drawings, there is required three directions in the rotation direction, and three directions in the linear direction in order to express all the actual repulsive forces. It can be realized by mounting motors corresponding to these directions in one device.

A section to input the bending of each finger, which is one embodiment of the data input device according to the 4th aspect of the present inven-

tion, will now be described. Fig. 6 is a perspective view thereof. A data input device 30 which can be commonly used with the force sensation exhibiting device of Fig. 1 is connected via a cable 3 to the information processing means2 , which is connected to the display means 4. The operator holds the data input device 30 by covering it with his/her hand. At that time, the tip portions of the first finger and the second finger are put on the depressions 33 and 34 on the surface of the data input device 30. The depressions 33 and 34 have pressure sensors 31a, 31b, 31c, 31d, 31e, 32a, 32b, 32c, 32d, and 32e mounted thereon to detect the force pushed by a finger. For example, when it is held by the right hand, in the case of the first finger, the belly portion of the finger is put on the depression 34, and the force to bend the whole first finger is detected by a pressure sensor 32d. Furthermore, the force to extend the first finger ahead is detected by a pressure sensor 32a, the force to bend the first finger forward is detected by a pressure sensor 32e, the force to shift the first finger to the right is detected by a pressure sensor 32b, and the force to shift the first finger to the left is detected by a pressure sensor 32c. As the pressure sensor, there can be used a pressure sensitive-type conductive rubber. Thus detected force of the finger is transmitted to the information processing means 2 which has stored the preliminarily housed relations between the pressure and the bending degrees of fingers, and by confirming on the display by means of a display means 4, it is used as the equivalent informations to the position informations of plural points by for example plural pointing devices. Furthermore, the informations relating to the force of the fingers can be used as the bending degrees of fingers or of what is equivalent to the fingers in order to operate an object in a remote area or a virtual object.

Fig. 7 is a sectional view of the data input device 30 described in Fig. 6 cut in the straight direction with the finger put thereon, that is, cut at right angles to the longer side direction of the depression. The depression 34 is shown in blank. Furthermore, the pressure sensor is drawn in the order of 32c, 32d and 32b from the right. And the pressure sensor is covered with a cover 36 so that the pressure sensor does not touch directly to the belly portion of the finger. The pressure change by the finger is transmitted through the amplifying circuits 35c, 35d and 35b to the information processing means 2.

Fig. 8 is a perspective view showing one embodiment of the data input device according to the 5th aspect of the present invention. The data input device 30 described in Fig. 6 and Fig. 7 is operated by being held by hand. The intention to bend the fingers based on the pressure of the belly portion of fingers input to the data input device 30 is transmitted through a cable 3 to the information processing means 2 and converted to the bending angles of virtual fingers. The bending angles of virtual fingers are displayed directly by the shape of fingers as shown by a virtual object 40 in the screen by the display means 4. The first finger and the second finger are drawn from the upper side and the thumb is drawn from the bottom side. At that time, the positional interrelations with the virtual object 41 is also displayed as an image. Since the operator carries out the operation of the data input device while seeing this display, he/she can operate easily the virtual object 41. Incidentally, the data input device used in Fig. 8 requires a detector for detecting the position and posture of the hand in the space, but the shape and the method to be attached are known conventionally, therefore the concrete description thereof is omitted in Fig. 8.

Fig. 9 is a structural sectional view showing one embodiment of the part which gives a repulsive force to the fingers of the data input device 30 according to the 6th aspect of the present invention. A pressure detecting sensors 32c, 32d and 32b are provided as in Fig. 7 with respect to the depression 34 on which the belly portion of the finger is put. Respective pressure sensors are mounted on the movable portions 41c, 41d and 42b, and by rotating the driving axes 42c, 42d and 42b, the pressure sensors can be controlled to move in the direction of the contact with the finger by the relation of gears of pinions and racks by rotating the driving axes 42c, 42d and 42b. In Fig. 9, the driving method is shown by an example of the rotation system, but it is clear that it is possible to drive the movable portions 41c, 41d and 41b by using linear type motors such as a voice coil motor. Furthermore, a displacement detecting means may be used instead of the pressure sensor.

Fig. 10 is a block diagram of a circuit illustrating the structure of the control system according to the 7th aspect of the present invention. The pressure informations P detected by the pressure sensors are transmitted through the amplifiers 35c, 35d and 35b to the information processing means 2. The information processing means 2 transmits a force instruction F with respect to the detected pressure p to the drive control means 45c, 45d and 45b by means of the following calculation:

$$F = k\,p$$

wherein, k is a constant in the range of
$-1 < k < 1$,

and when k is close to 1, a large repulsive force can be obtained, and a feeling to push a hard thing is obtained. When k is close to -1, since it acts in the direction to accelerate the force of the finger, a

feeling to push a soft thing is obtained. The information processing device 2 assumes that, for example, when the finger hits against the virtual object, k = 1, and when the finger does not hit against it, k = -1, and can freely express a hard feeling and a soft feeling by changing k. For example, it controls so that the detected pressure becomes equal to the value of the desired force sensation to be exhibited.

Incidentally, in the embodiments of Fig. 9 and Fig. 10, the pressure in all the directions with respect to the belly portion of the finger is detected, and the embodiments which can cause a repulsive force similarly to all the directions are taken up for the explanation. But it can easily be thought that it may be a device which can detect and control only the direction pushed by the finger. Furthermore, though the embodiment using a pressure sensor to detect the pressure is taken up for the explanation, the method to calculate the force pushed by the finger by utilizing the change of the motor with respect to the driving axes 42b, 42c and 42d and the drive load may be possible. Furthermore, in Fig. 6, there is described a case where only the belly portion at the tip of the finger can be detected and controlled, but it is obvious that the detection and control of the pressure of other portions of the finger can be possible in the same manner.

The structure to give a repulsive force to fingers and the control method thereof are described with reference to Fig. 9 and Fig. 10, but as a simple method, there may be used a method to let the finger acknowledge that the fingers contact a virtual object by using an oscillation instead of giving a repulsive force. In this case, it can be easily realized by oscillating the driving axes 42c, 42d and 42b by a motor in Fig. 9. The oscillation repeats to change, for example, abruptly in the direction of the repulsive force, and to change moderately in the reverse direction.

Furthermore, in the above mentioned embodiments, a direct-current motor is used as a motor, it is not necessarily to be a motor by an electromagnetic force, and it may be, for example, a so-called ultrasonic motor which utilizes the oscillation of a piezoelectric element.

The 8th aspect of the present invention will be described with reference to Fig. 8 again. Fig. 8 is a view also showing one embodiment which uses a data input device according to the 8th aspect of the present invention. The data input device (here, it is a force sensation exhibiting device) 30 described in Fig. 9 and Fig. 10 is operated held by hand. The intention to bend the fingers based on the pressure of the belly portion of the finger input to the force sensation exhibiting device 30 is transmitted via a cable 3 to the information processing means 2 to be converted to the bending angles of virtual fingers. The bending angles of virtual fingers are displayed just as the shape of fingers as shown in the virtual object 40 in the screen by the display means 4. At this time, the positional interrelation with the virtual object 41 is also displayed as an image. When the position of fingers in the screen contacts with the virtual object 41, the information processing means 2 displays the screen, whereby it is easily known that the positions of fingers in the screen contacts with the virtual object 41. At that time, the information processing means 2 sends the instruction to give a large repulsive force to the force sensation exhibiting device 30. Since the force sensation exhibiting device 30 gives a repulsive force to the fingers, the operator can easily know that the tips of his/her fingers contact with the virtual object 41 and as well as the image output from the display means 4, whereby an operation with higher quality can be realized. For example, when the virtual object 41 is not a rigid body, but a elastic plastic body such as a clay, a delicate deforming operation becomes possible.

Fig. 11 is a perspective view showing the structure that an auxiliary input means is provided on the common housing according to the 9th and 10th aspect of the present invention. In Fig. 11, the data input device 30 described with reference to Fig. 6 and the auxiliary input means 50, 51, 52 are mounted on the common housing 53. The auxiliary input means is composed of a grip 50 which is grasped by the operator, a polyaxes force sensor 52, and a lever arm 51 which connects them. The operator puts his/her right hand on the data input device 30, and grasps the lever arm 51 and the grip 50 of the auxiliary input means by the left hand. When the operator tries to move the position of his/her hand in a virtual environment in the display means 4, he/she operates the lever arm 51 of the auxiliary input means to the corresponding direction. When he/she tries to operate the lever arm 51 in the longitudinal, lateral, oblique or rotational directions, the force in the corresponding directions can be detected by a polyaxes sensor 52. Since the direction of the force given by the operator coincides with the direction in which the finger in the display means 4 is moved, the informations of the force can change the positions of fingers in the display means 4 by the information processing means 2. Furthermore, by setting so that the positions of fingers move a certain amount when a force is applied, it becomes possible that the fingers move in an infinitely large virtual space by making the time for applying the force longer. (The concrete principles and structures of the polyaxes sensor 52 are explained in "Force sensing-type sensor, Ogata, et al, Japanese Robotics Society, Vol. 6, No. 9, pp. 759 - 765, 1991) Thus,

when the left hand operates the lever arm 51 for the auxiliary input, the right hand performs the role to support and fix the whole input device, and conversely, when the right hand intends to grasp an object and applies a force to the palm, the left hand performs a role to support and fix the whole input device. Therefore, the operator can easily operates the input device, even if the whole input device is small and light.

Fig. 12 corresponds to the 11th aspect of the present invention, and is a perspective view showing another positional relationship between the auxiliary input means and the data input device portion different from that of Fig. 11. The auxiliary input means is composed of a lever arm 51 and a polyaxes force sensor 52, and a data input device portion (or a force sensation exhibiting device portion) 30 is fixed at the position of a grip 50 in Fig. 11. Thus, the operator can operate the auxiliary input simultaneously only by one hand. Concretely, by applying a force through the lever arm 51 toward the direction to which the operator intends to move it, while grasping the data input device portion (or a force sensation exhibiting device portion) 30 by the right hand, it becomes possible to move the fingers to the infinite distance in the display screen. Particularly in Fig. 12, since all the operation to apply a force can be performed by one hand, it becomes possible to support and fix the whole input device by the other hand, and the operator can easily operates the input device, even if the whole input device is small and light.

Incidentally, in Fig. 11 and Fig. 12, the embodiments in which the auxiliary input means is integrated with the data input device are illustrated, but for example in Fig. 11, the operation shown in Fig. 8 can be done by dismounting the data input device 30 and grasping it by hand to lift it.

Next, the 12th aspect of the present invention will be described with reference to Figs. 14, 15 and 16. Fig. 14 is a perspective view showing the holding state when the data input device or the force sensation exhibiting device 30 is cylindrical. Fig. 15 is a perspective view showing the holding state when the data input device or the force sensation exhibiting device 30 is spherical. Fig. 16 is a perspective view showing the contact face in the palm in the case of the two shapes. In the case of a cylindrical shape as shown in Fig. 14, the thumb and other fingers hold the device 30 so that the thumb opposes to other fingers. And in the case of a spherical shape, the device 30 is held so that the fingers cover the hemisphere face. In either case, the device 30 is held by hand. However, in the case of a cylindrical shape, since the thumb opposes to other fingers, the cylindrical face of the device 30 can be held so as to be covered by the palm portion. On the other hand, in the case of a spherical shape, since the oppositiveness of the thumb and other fingers is low, it is difficult to cover the device only by the palm to hold it, and the necessity to hold it by fingers increases. Furthermore, even if the device 30 can be held by the palm, the contact area corresponds to the holding by the palm is the part shown by hatching of a cross line in the case of a spherical shape, and it is narrower than the contact area of the cylindrical shape shown by hatching of an oblique line as shown in Fig. 16. Moreover, from the viewpoint of a friction, the cylindrical shape is advantageous. Incidentally, the explanation is done by a spherical shape here, the hemispherical shape is held in the same manner as in the spherical shape, whereby the content of the 12th aspect of the present invention is not affected. Furthermore, though depressions or pressure sensors for the fingers to put on are omitted to facilitate the illustration, it is needless to say that it is obvious from the results of Fig. 6, and the like.

Next, the 13th aspect of the present invention will be described with reference to Fig. 17. In Fig. 17, at the tip of a manipulator 60, a data input device or a force sensation exhibiting device 30 is mounted. The operator holds the device 30, and carries out the operation while seeing the display means 4. The shift of the position of the whole wrist is carried out while being restricted by the manipulator. The position of the whole wrist can be detected by the information processing means 2, by using the angle of each joint 61a, 61b and 61c of the manipulator 60. The calculated results are fed back to the operator 120 via the display means 4. Furthermore, the information processing means 2 controls the restriction of the manipulator 60. With regard to the control of restrictions, a force control, a compliance control and a position control is selected according to need. Thereby, it becomes possible to give a repulsive force to the operator 120 via a data input device 30 mounted at the tip of the manipulator 60. Incidentally, Fig. 17 is described by using a manipulator having three joints, but the present invention is not limited to the number of joints, and it is obvious that the present invention is applied to a manipulator with one joint and a manipulator with an infinite joints.

Fig. 18 is a structural sectional view showing one embodiment according to the 14th aspect of the present invention. Fingers 90 push via a soft housing (not shown) the pressure sensor 85 mounted on the barrel shaped leaf spring 84. The leaf spring 84 carries out a spring action by the push of the finger 90. The leaf spring 84 is fixed by gears 83a and 83b at the both ends, and the length of the bowstring can be changed by the rotating action of the gears 83a and 83b. When the length of the bowstring is made longer by driving the gears 83a

and 83b by motors 82a and 82b, the finger 90 can easily push downward and the spring becomes soft. On the contrary, when the length of the bowstring is made shorter, the finger 90 is pushed back upward, while the spring becomes hard. Thus, the softness (compliance) can be changed against the finger 90. The control circuit 80 calculates the necessary position with respect to the objective compliance to control the positions of motors 82a and 82b.

Figs. 19 and 20 are the views showing the waveform illustrating the action principles of the embodiment according to the 15th aspect of the present invention. The waveform of Fig. 19 shows the setting method of the objective compliance in order to give the sensation of a repulsive force in the direction of being pushed back, and the waveform of Fig. 20 shows the setting method of the objective compliance in order to give the sensation of a repulsive force in the direction of being pulled in. Since the action principles are the same, the explanation will be done by taking Fig. 19 as an example. The waveform of Fig. 19 is to repeat the actions to increase the objective compliance abruptly and to return it slowly to the original point. By doing this, since only the abrupt change can be sensed by a human body due to the nonlinearity of the human sense as described in the 1st aspect of the present invention, the operator feels it becomes harder. Since the actual finger is pushing the leaf spring 84 in Fig. 18 with a certain force, the finger is pushed back by the hardened portion, whereby the finger senses the repulsive force to be pushed back.

Fig. 21 is a structural perspective view showing one embodiment of the 16th and the 17th aspects of the present invention. In the state to hold the device 30, a switch 71 operable by the little finger not participating in the hold is provided. According to the present invention described above, it is necessary to give continuously a certain force in the bending direction of the finger, thus other actions cannot be done on the way. The 16th aspect of the present invention makes it possible. Namely, by pushing the switch 71 on the way of the operation, other actions can be performed in the state that the bending information of fingers remains as it is. It can be easily realized to perform the decision and processing based on the input of the switch 71 by the information processing means 2 (not shown). Furthermore, once the switch 71 is turned ON, there is no need to continue pushing by the finger to prevent the fatigue of the finger.

Fig. 22 is a perspective view to explain one embodiment of the operation according to the 17th aspect of the present invention, based on the similar consideration. The similar switch 71 can fix the position of the whole wrist. In Fig. 22, it is assumed that the whole wrist holding the device 30 carries out a reciprocating shift motion in turn in the directions of arrows (A), (B) and (C), which are the top right-hand direction in the paper and the reverse direction. At this time, when shifting to the direction of the arrow (A) and (C), the switch 71 is turned OFF, and when shifting to the direction of the arrow (B), the switch 71 is turned ON. Therefore, by setting that the change of the position and posture of the wrist is not input when the switch is ON, it is possible that only the shift in the direction of the arrow (A) and (C) is input. By repeating this operation, the designation of the position over the movable range of the arm becomes possible. Furthermore, by turning the switch 71 ON, there is no need to fix the arm at a specific position in the space, whereby the fatigue of the arm can be prevented.

Fig. 23 is a structural perspective view showing one embodiment according to the 18th aspect of the present invention. The basic structure is similar to that of Fig. 12 described as the embodiment according to the 11th aspect of the present invention. In Fig. 23, however, the shape of the device 30 is cylindrical, and a switch 71 which is the essential requirement in the 18th aspect of the present invention is provided. Holding the device 30, the operator applies a force to the polyaxes sensor 52 which is an auxiliary input means by the whole wrist holding the device 30. The switch 71 can be operated by the other hand not holding the device 30. The information processing means 2 (not shown) can perform the functions described in the 16th or the 17th aspect of the present invention by the operation of the switch 71.

Incidentally, though the switch used in the description of the embodiments according to the 16th, 17th and 18th aspects of the present invention is only one, respectively, switches correspond to each of them may be provided respectively, or only the switch corresponding to any one or two of the present invention may be mounted.

Fig. 24 and Fig. 25 are the views for illustrating the 19th aspect of the present invention. Fig. 24 is a circuit block diagram for converting the force informations to the positional informations such as bending of fingers, and Fig. 25 is a view of a waveform showing the operation results thereof. In Fig. 24, the force informations converted to the voltage informations by a force-voltage converter 75 (pressure sensor output) is connected to the IC1 circuit and the resistance R1. The IC1 circuit is a comparison circuit to compare the force informations and the reference voltage Vref. When the force information is small, the switch SW is turned ON, and when it is large, the switch SW is turned OFF. When the switch SW is OFF, an inversion integral circuit is constituted by a resistance R1, a

capacitor C1 and an IC2 circuit to invert and integrate the force informations and to input the inverted and integrated results to an IC3 circuit. IC3 circuit is a differential circuit, and inverts the voltage by making the reference voltage Vref as the standard to obtain uninverted integrated results. The reference voltage Vref is selected in the vicinity of the threshold for the determining if it is a large force or not. On the other hand, when the switch SW is ON, an inversion circuit is constituted by an IC2 circuit, a resistance R1 and a resistance R2, and the inverted results are transmitted to the IC3 circuit. Namely, the circuit in Fig. 24 carries out the integration when the force information is larger than the reference voltage, and when the force information is smaller than the reference voltage, it obtains the direct output. Fig. 25 shows the operation waveform. In the drawing, the force information is shown by a solid line, and the output is shown by an one dot chain line. When the force information as shown by the solid line of Fig. 25 is input, if the force information is smaller than the reference voltage Vref, the output is the same, and if it is larger than the reference voltage Vref, the integration action is carried out as shown by the one dot chain line. By using such means, there is no need to continue applying a big force necessary to turn ON. Thus, even if the force is a little loosened, the ON state can be maintained, and the fatigue of fingers can be prevented.

Fig. 26 and Fig. 27 are the views for illustrating one embodiment according to the 20th aspect of the present invention. Fig. 26 is a circuit block diagram for converting the force informations to the positional informations such as bending of fingers, and Fig. 27 is a waveform diagram showing the operation results thereof. In Fig. 26, the force informations converted to the voltage informations by a force-voltage converter 75 (pressure sensor output) is connected to an IC circuit, a diode D and a resistance R2. The diode D, the capacitor C and the resistance R1 constitute a maximum value-holding circuit (or peak hold circuit), and when the input voltage becomes low, it is held by the charge of the capacitor for a while. The charge of the capacitor is discharged slowly by the resistance R1. The IC is a comparison circuit to compare the force informations and the reference voltage Vref, and to control the opening/closing of the switch SW according to the results. The reference voltage is set similarly as in the 19th aspect of the present invention. When the force information is larger than the reference voltage Vref, the switch SW is turned OFF, and when it is smaller than the reference voltage, the switch SW is turned ON. When the switch SW is ON, the output voltage is connected via a resistance R2 to the force informations, therefore the output is substantially equal to the force information. Namely, the circuit of Fig. 26 carries out an operation to substantially hold the maximum value of the force informations when the force information is larger than the reference voltage Vref, and when it is smaller than the reference voltage Vref, the circuit operates so that the output becomes substantially equal to the force information. Fig. 27 shows the operation waveform. In the drawing, the force information is shown by a solid line, and the output is shown by an one dot chain line. When the force information as shown by the solid line of Fig. 27 is input, if the force information is smaller than the reference voltage Vref, the output is the same, and if it is larger than the reference voltage Vref, the maximum value-holding operation is carried out. By using such means, there is no need to continue applying a big force, and the fatigue of fingers can be prevented.

Fig. 28 is a perspective view showing one embodiment according to the 21st aspect of the present invention. For the ease of presentation, the second finger and the third finger and the little finger are omitted, and the device 30 is held by the thumb and the first finger. Namely, in the situation holding the device 30, the portion of the tip joint of the thumb pushes the pressure sensor 131a, and the next portion pushes the pressure sensor 131b. Similarly, it is designed so that the first finger contacts with the pressure sensor 132a, 132b and 132c. Accordingly, the intention to bend the joint of the tip of the thumb is detected by the pressure sensor 131a, and the intention to bend the next joint of the thumb is detected by the pressure sensor 131b. Similarly, the intention to bend the joint of the tip of the first finger is detected by the pressure sensor 132a, and the intention to bend the next joint of the first finger is detected by the pressure sensor 132b. The intention to bend the joint closest to the palm can be detected by the pressure sensor 132c. Thus, the intention to bend each joint of all fingers toward the palm can be detected by the pressure sensors provided corresponding to the surface of the device 30. On the other hand, the intention to shift in the direction of the inner face of the palm, which is another degree of freedom of the finger, becomes the motion to the right and left direction with regard to the direction of the belly portion of the finger, whereby it can be detected by providing the pressure sensors 32b and 32c at the right and at the left of the direction of the belly portion of fingers as shown in Fig. 6.

Fig. 29 is a perspective view (a) in the state holding the device 30 and a partial sectional view (b) showing one embodiment according to the 22nd aspect of the present invention. In Fig. 29 (a), the both ends of a cylindrical device 30 being held are in the form that semicylindrical shape having

fringe portions are combined by a screw 12. Namely, the sectional view of the both ends is as shown in Fig. 29 (b). Furthermore, the part held by an actual hand is in the form of two semicylindrical shapes linked therewith. The connection thereof can be realized by, for example, linking the gap between the two semicylindrical shapes via an elastic body or an elastic plastic body 125. By fastening the screw 126, the diameter of the cylindrical shape becomes small, and by loosening the screw 126, the diameter of the cylindrical shape becomes large. Therefore, an operator who has large hands uses it by making its diameter large by loosening the screw for the ease of grasp, and a person who has small hands like a child uses it by making its diameter small by fastening the screw for the ease of grasp.

Next, one embodiment according to the 23rd aspect of the present invention will be described with reference to Fig. 30, Fig. 31 and Fig. 32. Fig. 30 is a sectional view of a part of the device 30 similar to that of Fig. 7. The Fig. 30 (a) shows the situation where the finger 90 is small, and (b) shows the situation where the finger 90 is large. As shown in Fig. 30 (a), when the finger 90 is small, there exists a state where a pressure is not applied to any of the pressure sensors 32b and 32c which detect the intention to move the finger to right and left. On the contrary, when the finger 90 is large as shown in Fig. 30 (b), the situation is that a pressure is applied to the both pressure sensors 32b and 32c.

Fig. 31 shows a detected result of the pressure sensors 32b and 32c in the state of Fig. 30, and the lateral axis x shows the magnitude of the force to bend the finger, taking a positive number to the right. As in Fig. 30, Fig. 31 (a) shows a detected result in the case that the finger 90 is small, and Fig. 31 (b) shows a detected result in the case that the finger 90 is large. As shown in Fig. 31 (a), if the finger 90 is small, there is a gap between the finger and the pressure sensors 32b and 32c, whereby when the force x is small, the sensor 32 cannot detect the force, and it is not until the force x becomes larger than x1, the sensor 32 can detect the force. Similarly, when the force x is larger than x2 (the negative value), the sensor 32b cannot detect the force due to the gap, and it is not until the force x becomes smaller than x2, the sensor 32b can detect the force. In Fig. 31 (b), since the finger 90 is large, a pressure is always applied to the pressure sensors 32b and 32c. Though the finger deforms itself more or less to match with the shape, a force f1 is always applied to the direction not applying a force. Therefore, the values detected by the pressure sensors 32b and 32c differ according to the size of the finger.

Fig. 32 is a circuit block diagram in order to avoid this influence. Namely, it obtains the bending informations of a finger in the right and left directions by comparing the detected results by the pressure sensors 32b and 32c for detecting the intention to move the finger to right and left with a comparison means. When the finger small and there is no intention to bend it to the right and left directions, the output of the two pressure sensors 32b and 32c are both 0, and even if they are compared by the comparison means 140, the value remains 0. On the other hand, when the finger is large and there is no intention to bend the finger, the output value of the two pressure sensors 32b and 32c are the same value, whereby the compared result by the comparison means 140 becomes 0. When there is an intention to bend the finger, any one of the two pressure sensors 32b and 32c receives a clearly large force, whereby the outputs of the two sensors can be compared to make it the bending informations of the finger. Namely, the intention to bend the finger to right and left can be obtained without being affected by the size of the finger.

Fig. 33 shows one embodiment according to the 24th and 25th aspects of the present invention. As already described, the pressure sensor 132 which detects the intention to bend the finger also detects the trembles of fingers and unevenness of the force, when it detects the force to bend the finger. The intention informations containing these unnecessary informations are input to the low-pass filter 111. The low-pass filter 111 attenuates the component of rapid changes such as trembles. The informations passed through the low-pass filter 111 are transmitted to the means for calculating the dead zone 112. The means for calculating the dead zone 112 carries out a process which does not react to a minute value. Thereby, the influences of the case where small forces are applied unconsciously, for example, a case where when bending a finger not related to the intention, the influence appears to the adjacent finger, can be removed. In Fig. 33, the description was made joining the 24th aspect and the 25th aspect of the present invention into one embodiment, it is needless to say that only the low-pass filter 111 or the means for calculating the dead zone 112 can obtain a certain effect. Incidentally, if the order of the low-pass filter 111 and the means for calculating the dead zone 112 is reversed, the average value of the output results of the means for calculating the dead zone 112 varies depending on the strength of the trembles of hands and the like, therefore it is not preferable.

Fig. 34 is a perspective view showing the state holding the device 30, and showing the preconditions relating to the 26th and 27th aspects of the

present invention which will be described now. The device 30 is cylindrical, and Fig. 34 is a sectional view of the part held by the thumb and the first finger. In Fig. 34, the intention to bend the tip joint of the thumb is detected by the pressure sensor 131a, and the intention to bend the next joint is detected by the pressure sensor 131b. Similarly, the intention to bend the tip joint of the first finger is detected by the pressure sensor 132a, and the intention to bend the next joint is detected by the pressure sensor 132b, and the intention to bend the base joint is detected by the pressure sensor 132c. In Fig. 34, the state that a force is not applied to the pressure sensor 132a is shown. Furthermore, there is a case where a pressure is applied in the part between the thumb and the first finger in order to hold the device 30. Fig. 35 shows the magnitude of each pressure and the direction thereof in the state holding the device 30. In Fig. 35, it is assumed that the force at the pressure sensor 131a is F131a, the force at the pressure sensor 131b is F131b, the force at the pressure sensor 132b is F132b, and the force at the pressure sensor 132c is F132c. Since the force at the pressure sensor 132a is zero, it does not appear in Fig. 35. Incidentally, the force at the part 130 between the thumb and the first finger is assumed to be zero, being regarded as the force for holding the device 30. In Fig. 35, all the four forces F131a, F131b, F132b, and F132c are the vector volume toward the origin of the cylinder. Since the device 30 is held and stopped, the composite vector (sum of the vector) is zero. Namely, in Fig. 35, the force is analyzed to the direction of the force F131a and the component of the directions crossing at right angles therewith, F131bx, F131by, F132bx, F132by, F132cx and F132cy, and the sum of F131a, F131bx, F132bx and F132cx, and the sum of F131by, F132by and F132cy are zero, respectively.

If the force is increased to bend largely the tip of the thumb, the force F131a increases. Then, in order to hold stably the device 30, the forces of other fingers must be increased. At this time, however, other fingers does not apply the force with an intention. Therefore, the forces of other fingers cannot be larger than the force of the thumb, and must be small. That is, the small forces are regarded not to be connected with the intention to bend the finger.

Fig. 36 is a circuit block diagram showing one embodiment according to the 26th aspect of the present invention. The informations of the intention to bend each finger, containing the informations to hold the device 30, detected by the pressure sensor group 145 comprising the pressure sensors 131a, 131b, 132a and 132b described in Fig. 34, are transmitted to the arithmetic means 146 for taking out the minimum value and the subtraction means 147. The arithmetic means 146 takes out the minimum force vector among the force being not zero, from the force informations. The minimum force vector taken out is transmitted to the subtraction means 147. The subtraction means 147 subtracts the value of the minimum force vector from each force vector based on the positional data 148 of each sensor. The subtracted value is used as the bending informations of fingers. Incidentally, the output of the pressure sensor from which the minimum force vector is detected is made zero. Since the force vector which is relatively small is considered to have no relations with the intention to bend, it can be regarded to satisfy the holding conditions of the device 30. And by subtracting the value from each force vector, the value becomes approximate to that of the force vector necessary for the hold to be subtracted, and the subtracted informations are close to the intention to bend the fingers.

Fig. 37 is a circuit block diagram showing another embodiment according to the 26th aspect of the present invention. The detailed description of the part having the same structure with that of Fig. 36 is omitted. The informations of the intention to bend each finger containing the informations to hold the device 30, detected by the pressure sensor group 145 are transmitted to the arithmetic means 149 for taking out the force vector below a certain level and the subtraction means 147. At the arithmetic means 149, only the force vector below a certain level is taken out, and transmitted to the force vector subtraction means 147. At the force vector subtraction means 147, as in the case of Fig. 36, the sum of the detected value of the force vector below a certain level is subtracted from the informations detected by the pressure sensor group 145. The detected value is used as the bending informations of fingers. Incidentally, the output of the pressure sensor from which the force vector below a certain level is detected is made zero. As in the case of Fig. 36, since the force vector which is relatively small is considered to have no relations with the intention to bend, it can be regarded to satisfy the holding conditions of the device 30. And by subtracting the value from each force vector, the value becomes approximate to that of the force vector necessary for the hold being subtracted, and the subtracted informations are close to the intention to bend the fingers.

Fig. 38 is a circuit block diagram showing another embodiment according to the 26th aspect of the present invention. The detailed description of the part having the same structure with that of Fig. 37 is omitted. The informations of the intention to bend each finder containing the informations to hold the device 30, detected by the pressure sen-

sor group 145 are transmitted to the maximum value-detecting means 141, the calculating means 149 for taking out the force vector below a certain level and the subtraction means 147. At the maximum value-detecting means 141 calculates the maximum value of the input value. The obtained maximum value information is transmitted to the threshold calculating means 142. The result of the threshold calculating means 142 is transmitted to the arithmetic means 149. The threshold calculating means 142 obtains the threshold by, for example, multiplying the input value by a certain coefficient. At the arithmetic means 149, only the force vector below a certain threshold level determined by the threshold calculating means 142 is taken out, and transmitted to the force vector subtraction means 147. At the force vector subtraction means 147, as in the case of Fig. 37, the value of the force vector below a certain threshold level taken out is subtracted from the informations detected by the pressure sensor group 145. The subtracted value is used as the bending informations of fingers. As in the case of Fig. 37, since the force vector which is relatively small is considered to have no relations with the intention to bend, and the threshold value varies associating with the maximum value with the largest intention, it can be regarded to satisfy the holding conditions of the device 30 continuously.

Fig. 39 is a process block diagram showing the signal processing method in one embodiment according to the 27th aspect of the present invention. In Fig. 39, the informations of the intention to bend containing the informations for holding detected by the pressure sensor group 145 are transmitted to the neural network-type arithmetic means 143, and only the informations of the intention to bend the fingers are taken out as the bending informations of fingers. Fig. 40 shows the details of the neural network-type arithmetic means 143, and comprises a neural cell (or neuron) group having three layers, input layers, intermediate layers and output layers, and a force informations to bend the joint of each finger is input to each neural cell (or neuron) (NI_1,NI_2,...NI_k) of the input layer. Each neural cell (or neuron) gives a certain weight to the input informations to determine the output by the threshold logic signal processing (sgn function) or the corresponding signal processing (sigmoid function, and the like). The weight is preliminarily determined by a prior study. The output informations of the neural cell (or neuron) in the input layer is transmitted to each neural cell (or neuron) in the intermediate layer (NM_1,NM_2,...NM_{k+1}). Each neural cell (or neuron) in the intermediate layer gives and adds a certain weight to the output informations of each neural cell (or neuron), and carries out the signal processing similar to that of the neural cell (or neuron) in the input cell.. The weight is preliminarily determined by a prior study. Each output information of the neural cell (or neuron) in the intermediate layer is transmitted to each neural cell (or neuron) in the output layer (NO_1,NO_2,...NO_k). The neural cell (or neuron) in the output layer gives and adds a certain weight to the output of the neural cell (or neuron) in the intermediate layer. The added results are used as the bending informations of the joint of each finger.

The method of prior study of the weight at the time of input to each neural cell (or neuron) in Fig. 40 will now be described. The study is carried out so that the error among the result calculated by the neural network, the data of angles to be bent and the force data given by the actual finger becomes minimum. As the study method, a back propagation method is well known. (For example, Rumelhart, D.E., McGlelland, J.L. and the PDP Research Group: Parallel Distributed Processing: Explorations in the Micro-structure of Cognition, Vol. 1, pp.318-362, MIT Press (1986)) By these study, the weight of the input phase of each neural cell (or neuron) is determined. Thereby, from the informations of the intention to bend the fingers containing the information to hold the device 30, only the informations of the intention to bend the fingers are taken out, whereby makes the data input having higher accuracy becomes possible. Namely, since the relation between the intention to bend the fingers and the force while holding the device has been preliminarily identified as the neural network, by inputting the detected result to the neural network, the informations of the intention to bend the fingers can be taken out as an output.

Incidentally, the 27th aspect of the present invention was described by using a three layered neural network-type arithmetic means, but it is obvious that other method of neural network-type arithmetic means may be used.

Figs. 41, 42 and 43 are views illustrating briefly the principles of the ultrasonic vibration motor used in the 28th, 29th and 30th aspects of the present invention. Please refer to the detailed description included in "Kawasaki, et al, U.S. Patent No. 4,853,579". Fig. 41 shows the basic structure of the ultrasonic vibration motor, in which an elastic body 150 is sticked on the two-layered piezoelectric ceramics 151a and 151b. The two-layered piezoelectric ceramics 151a and 151b are polarized so that the polarized directions are alternated per the ($\lambda/2$) section, and sticked so that the phase of the two layers is shifted by ($\lambda/4$). When the alternating signal in which the phase is shifted by 90 degree with each other in the resonant frequency is applied to these two-layered piezoelectric ceramics 151a and 151b, the deformation shown in Fig. 42 is caused. Fig. 42 shows the deformation including

the elastic body 150 in the time series, and with the lapse of time, the deformation varies in the order of (a), (b), (c), (d) and (e) of Fig. 42. Furthermore, (e) is identical with (a), and repeats (b), (c), and so on. Overall wave motion shifts from the left to the right. Seeing the behavior at one point in the elastic body in each time, it is understood that it draws the elliptical orbit rotating couterclockwise as shown in Fig. 42 (f). In this situation, it is Fig. 43 that shows the situation in which a moving body 155 is placed on the elastic body 150. In Fig. 43, at the point where the elastic body 150 contacts with the moving body 155, the contact portion carries out an elliptical motion rotating counterclockwise, and the elastic body moves to left at the contact point. Therefore, a force in the left direction is generated to the moving body 155, and if the moving body 155 overcomes the static friction, it starts to move to the left direction. Thus, it becomes possible for the ultrasonic vibration motor to shift or give force to the optional object placed on the elastic body 150.

Fig. 44 shows one embodiment according to the 28th, 29th and 30th aspects of the present invention using the ultrasonic vibration motor. In Fig. 44, when a finger is put on the device 30, an ultrasonic vibration motor 156 is provided to the place where the belly portion of the finger contacts, below which a pressure sensor 32 for detecting the pressure in the vertical direction is provided. The detected results by the pressure sensor 32 is input to the reciprocal arithmetic means 157 to obtain the reciprocal value of the pressure. The obtained reciprocal value of the pressure is input to the multiplying means 158 to multiply it by the force objective value. The multiplied results are transmitted to the drive circuit 159, and drives the ultrasonic vibration motor 156. The ultrasonic vibration motor 156 generates a force Fx in the face where the belly portion of the finger contacts by the drive circuit 159. The belly portion of the finger can sense the repulsive force in the horizontal direction by this force Fx. The force Fx given to the finger from the ultrasonic vibration motor 156 varies depending on whether the finger pushes strongly or not. Namely, the stronger the finger pushes the face of the elastic body of the ultrasonic vibration motor 156, the larger force can be obtained. Therefore, even if the same drive instruction is given, if the pushing force of the finger is large, a large repulsive force can be obtained, and if the pushing force of the finger is small, only a small repulsive force can be obtained. Since the pushing force can be detected by the pressure sensor 32, by getting the reciprocal and multiplying it by the objective value of the repulsive force, the influences by the pushing force can be canceled, and the repulsive force along the objective value can be obtained.

On the other hand, the information of the force by which the surface of the finger opposes against the generated repulsive force is a load of the ultrasonic vibration motor 156, whereby it can be calculated from the electric current of the drive circuit 159. However, as described above, since the ultrasonic vibration motor 156 is driven by the alternating current, the current is calculated as an average current by the average current detecting means 160.

Incidentally, in the 29th and 30th aspect of the present invention, the explanation was made by using an ultrasonic vibration motor using the piezoelectric ceramics, but as the means to generate the oscillatory wave, it is needless to say that it is not limited to the piezoelectric ceramics, and the magnetic body and the like can cause the similar effects.

In the above embodiments, the explanation was made by taking an example in which the force sensation exhibiting device for hands or the data input device for hands and the information processing means are connected via a cable, but it is also possible to realize the information communication by means of the radio wave or the light, by mounting the supply source in the force sensation exhibiting device for hands or the data input device for hands.

As is obvious from the above description, the above-mentioned respective inventions can be used extremely easily by a simple action of "grasping", without mounting a glove and the like.

Furthermore, according to the 1st, 2nd, 3rd and 13th aspects of the present invention, the repulsive force which the palm receives when operating an object, e.g. in the case of holding a virtual object can be exhibited by a relatively easy method. And the 4th and 5th aspects of the present invention utilizes the pressure at the tip of the finger, and the data input operation to the information processing means is made simple in the case where the similar skillful action is necessary. In the 6th, 7th, 8th and 14th aspects of the present invention, the data input operation to the information processing means based on the skillful action can be made simple, by making it possible to give a repulsive force or the feeling of the repulsive force to the fingers when grasping a virtual object. The 9th, 10th and 11th aspects of the present invention makes it possible to input the data of the substantially infinite distance, and the 12th aspect of the present invention makes the grasp easy. The 16th, 17th and 18th aspects of the present invention makes it possible to interrupt the operation easily, or input a wide range of positions without taking unreasonable postures. And the 19th and 20th aspects of the present invention eliminates the necessity for the fingers to apply a force continuously,

and the fatigue of the fingers is decreased.

Furthermore, according to the 21st aspect of the present invention, the intention corresponding to the bending of each joint of fingers can be detected by the detecting means corresponding to the bending of each joint, whereby operations which require complex motions of fingers becomes possible. The 22nd and 23rd aspects of the present invention make it possible to correspond to the persons having different palm sizes, or different thickness or size of fingers, whereby the same device can be used from children to adults. The 24th and 25th aspects of the present invention can remove trembles of fingers, fine variations such as unevenness of the force, and faint force, to smooth the actions of virtual fingers or fingers in remote area. The 26th and 27th aspects of the present invention remove the influences of the force relating to the holding of the device but not relating to the intention, and can take out only the informations relating to the intention to input complex actions of fingers. In the 28th and 29th aspects of the present invention, it becomes possible to generate a force in the direction of the inner surface of the finger, and also to generate a repulsive force against the direction thereof. The 30th aspect of the present invention can detect a force given by a finger to the inner direction of the belly portion of the finger to input complex actions of fingers.

Claims

1. A force sensation exhibiting device comprising
   a housing which can be grasped by a hand,
   at least one rotatably or linearly movable motor contained in the housing ,
   an input section where repulsive force informations are input, and
   control means for driving and controlling said motor according to the repulsive force informations, wherein
   a force sensation is given to said hand by a drive of said motor.

2. A force sensation exhibiting device according to claim 1, wherein
   a motor corresponding to a force vector is intermittently driven in a direction reverse to a force vector of the force sensation to be exhibited.

3. A force sensation exhibiting device according to claim 2, wherein
   a motor corresponding to a force vector is intermittently driven so that a torque is proportional to a magnitude of said vector, and
   in the intermittently driving, a period of turning off the motor is longer than a period until said activated motor stops.

4. A force sensation exhibiting device according to claim 2, wherein
   activating motion, moving in the reverse direction, and stopping motions are repeated , in which
   a motor corresponding to a force vector is activated so that a torque is proportional to a magnitude of said vector, and after being moved in a certain distance or a certain angle, activated in an extremely low torque in a direction reverse to that of the former activation, and after returns to a position or an angle before said activation is initiated, said motor is stopped.

5. A data input device comprising
   a housing which can be grasped by a hand,
   said housing being equipped with detection means for detecting a displacement or a pressure at a portion on which fingers are put at a time of the grasping of the hand, to make it possible to input a data.

6. A data input equipment which comprising
   a data input device according to claim 5, and
   control means for controlling bending of remote or virtual fingers or the like in response to output of said detection means.

7. A data input equipment which comprising
   a data input device according to claim 5,
   calculating means for carrying out image display calculations based on the input data thereof, and
   image display means for displaying a state of at least two fingers, such as positions, postures and bending on a basis of the calculations.

8. A force sensation exhibiting device comprising
   a housing which can be grasped by a hand,
   said housing being equipped with detection means for detecting a displacement or a pressure and repulsive force generating means for generating a pressure in a direction reverse to that of said detected displacement or pressure ,at a portion on which fingers are put at a time of the grasping of the hand.

9. A force sensation exhibiting device according to claim 8, wherein
   the repulsive force generating means can

change a position of the detection means for detecting said displacement or pressure, and is equipped with control means therefor.

10. A force sensation exhibiting device according to claim 8, comprising

vibrating means which can generate a vibration at a portion where a repulsive force is given when the repulsive force is required, instead of the repulsive force generating means.

11. A force sensation exhibiting device according to claim 10, wherein

the vibration generated by the vibrating means is an vibration which repeats to change abruptly in a direction of said repulsive force and change moderately in a reverse direction thereof.

12. A force sensation exhibiting device comprising,

a housing which can be grasped by a hand,

said housing being equipped with detecting means for detecting forces of plural axes respectively and repulsive force generating means for generating a pressure in a direction reverse to the detected forces of said axes, at a portion on which fingers are put when being grasped.

13. A force sensation exhibiting device according to any one of the claims 8 to 12, comprising

control means for controlling the repulsive force generating means so that the detected pressure becomes substantially equal to a desired value of a force sensation to be exhibited.

14. A data input equipment which comprising

a force sensation exhibiting device according to claim 8,

calculating means for calculating a force sensation value for exhibition based on output from said force sensational exhibiting device, and

image display means for displaying positions, postures and bending states of at least two fingers on a basis of calculation results from said calculating means.

15. A data input device comprising

any one of force sensation exhibiting devices or data input devices of claims 1 to 13, and

auxiliary input means for inputting state informations such as positions and postures of a whole fingers.

16. A data input device according to claim 15, wherein

said auxiliary input means is composed of force detecting means of plural axes.

17. A data input device according to claim 16, wherein

as inputs to said force detecting means of plural axes, changes of position and posture of the force sensation exhibiting device of claim 13 are input.

18. A data input device ,wherein

the auxiliary input means and the force sensation exhibiting device or the data input device of the any one of the claims 15 to 17 are mounted on a common housing.

19. A data input device according to claim 18, wherein

the force sensation exhibiting device or the data input device and said auxiliary input means are disposed so that they can be operated by separate hands of one operator.

20. A data input device which comprising

a force sensation exhibiting device or a data input device according to any one of the claims 1 to 13,

an arm portion and

a polyaxes force sensor section,

said force sensation exhibiting device or a data input device being connected to one end of said arm portion and said polyaxes force sensor section being connected to the other end of the arm portion, so that by an operation to change a whole position of said force sensation exhibiting device or the data input device, a force input corresponding to the operation to change is applied to said polyaxes force sensor section.

21. A device according to claim 5 or claim 8, wherein

the shape of a section grasped by hand is substantially cylindrical.

22. A data input equipment wherein

a data input device according to claim 5 is mounted at a tip of a manipulator which is possible and controllable to shift a plural degrees of freedom of positions and postures, and

a repulsive force is generated to said data input device by said manipulator.

23. A force sensation exhibiting device comprising

a barrel shaped leaf spring,

an adjusting means for changing a radius of said beam, and

control means for controlling said adjusting means, wherein a force sensation is given to fingers put on an approximately central portion of an arc of said beam.

24. A force sensation exhibiting device according to claim 23 comprising

means for oscillatingly changing the radius of the spring, wherein

said oscillating wave form has a wave form which repeats abruptly increasing hardness in a direction of giving a repulsive force, and moderately decreasing the hardness in a reverse direction to the direction of giving the repulsive force.

25. A data input equipment according to claim 6, 7 or 14, wherein

a switch operable by fingers is provided, by which input of a change of bending of fingers is temporarily stopped.

26. A data input equipment according to claim 6, 7 or 14 comprising

detecting means for detecting a position or a posture of a housing and

a switch operable by fingers not participating in the grasp is provided, wherein

a utilization of informations of positions or postures from said detecting means is temporarily stopped by said switch.

27. A data input equipment according to claim 15, wherein a switch operable by hand or an auxiliary input means is provided, by which input of the change of bending of fingers is temporarily stopped.

28. A data input equipment according to claim 15, wherein

a switch operable by a hand or auxiliary input means is provided, and

input of informations of positions or postures of the whole fingers is temporarily stopped by the switch.

29. A device/equipment according to any one of the claims 5 to 28, wherein

data is input based on an integral value or incomplete integral value of a force detected by the detecting means.

30. A device/equipment according to claim 29, wherein

the integral value or the incomplete integral value are utilized when a value of the detected force exceeds a certain value, and when the value of the detected force is below a certain value, a data is input by the value itself of the detected force.

31. A device/equipment according to any one of the claims 5 to 28, wherein

a data is input by utilizing a value of a maximum value or the like of the detected force for a certain period by holding the maximum value or the like .

32. A device/equipment according to claim 31, wherein

when the force value exceeds a certain value, the maximum value or the like is used and when the force value is below a certain value, a data is input by the force value itself.

33. A data input device according to claim 5 comprising

a housing portion which can be grasped by a hand, wherein a data can be input by providing detecting means for detecting a displacement or a pressure at each section of the housing with which finger belly portions between each joint of a finger contacts when being grasped.

34. A data input equipment comprising

a data input device according to claim 33, which controls bending of each joint of fingers or the like in a remote area, or of virtual fingers according to the detected force.

35. A data input device according to claim 21 comprising

diameter-adjusting means for adjusting a size of a diameter of said substantially cylindrical shape.

36. A data input device according to claim 35, comprising

said diameter-adjusting means is provided at a portion with which a hand does not contact when being grasped by hand.

37. A data input device according to claim 35, wherein

when being grasped by a hand, said diameter-adjusting means is so provided as to be in outer side than between a thumb and a little finger of the fingers.

38. A data input device according to claim 35, wherein

said diameter is adjusted by a plastic body equipped in a part of a portion where a hand is

located when being grasped by a hand.

39. A data input device comprising
a housing portion which can be grasped by a hand, and
detecting means for detecting a displacement or a pressure being provided respectively in respective parts with which each finger belly portion contact when being grasped, wherein
the detecting value is to be a difference between the detected values of two detecting means among respective detecting means.

40. A data input device according to claim 5, wherein
a low-pass filter is provided against the detected displacement or pressure and a value passed through the filter is to be the input data.

41. A data input device according to claim 5, wherein
means for calculating a dead zone is provided which regards as there is no input when the detected displacement or pressure is below a certain value, and
value passed through said means for calculating the dead zone is to be as the input data.

42. A data input device comprising
a housing portion which can be grasped by a hand,
detecting means for detecting a displacement or a pressure provided at a portion of the housing portion on which fingers are put when being grasped,
a low-pass filter through which the detected displacement or the pressure being made to pass , and
means for calculating a dead zone which regards as there is no input when the displacement or the pressure passed through the filter is below a certain value, wherein
value passed through the means for calculating the dead zone is to be the input value
.

43. A data input device according to claim 5, which subtracts a detected resulting value which is a minimum but not zero among the detected resulting values of the plural detecting means which are provided at such portions of the housing with which finger belly portions between each joint of the fingers contact at a time of grasping , from the respective detected resulting values , and makes the subtracted value to be the input data.

44. A data input device according to claim 5, which subtracts a sum of the detected resulting values which are below a certain value , from the respective detected resulting values of the plural detecting means which are provided at such portions of the housing with which finger belly portions between each joint of the fingers contact at a time of grasping, and makes the subtracted value to be the input data.

45. A data input device according to claim 5, which subtracts a sum of the detected resulting values which are below a certain value which is obtained from a maximum displacement or pressure detected by the plural detecting means which are provided at such portions of the housing with which finger belly portions between each joint of the fingers contact at a time of grasping, from the respective detected resulting values of the plural detecting means , and makes the subtracted value to be the input data.

46. A data input device according to claim 5, which identifies in advance an interrelationship between the detected resulting value of the displacement or pressure and an intention to bend fingers of a person who grasps , by using a neural network calculating means in which the detecting resulting value is to be an input and the intention is to be an output, and
inputs the detected resulting values to the identified neural network to take out fingers bending informations as an output to use it as the input data.

47. A force sensation exhibiting device which is equipped with an ultrasonic vibration motor comprising an electric-mechanical transducing element and an elastic body sticked thereon which generates a force in a same face as a finger belly portion face , at such portions with which the finger belly portion contacts at a time of grasping, and also equipped with detecting means for detecting a displacement or a pressure in a vertical direction against the face of the finger belly portion at a lower part of said ultrasonic vibration motor, and drives said ultrasonic vibration motor by using the detected output of the detecting means.

48. A force sensation exhibiting device according to claim 47, which comprises a reciprocal converting means for detecting a displacement or a pressure in the vertical direction against the

face of the finger belly portion to determine a reciprocal of the displacement or the pressure, and means for determining a product of an objective value of a force to be given in the face of the finger belly portion and said reciprocal , and drives said ultrasonic vibration motor in proportion to the product.

49. A force sensation exhibiting device according to claim 47 or claim 48, wherein the electric-mechanical transducing element is an piezoelectric ceramics.

50. A force sensation exhibiting device which is equipped with an ultrasonic vibration motor comprising an electric-mechanical transducing element and an elastic body sticked thereon which generates a force in a same face as a finger belly portion face , at such portions with which the finger belly portion contacts at a time of grasping, and makes an average current of the ultrasonic vibration motor to be a magnitude of a force in a contacting face of said finger belly portion ,, and drives said ultrasonic vibration motor based on the magnitude of the force.

Fig. 1

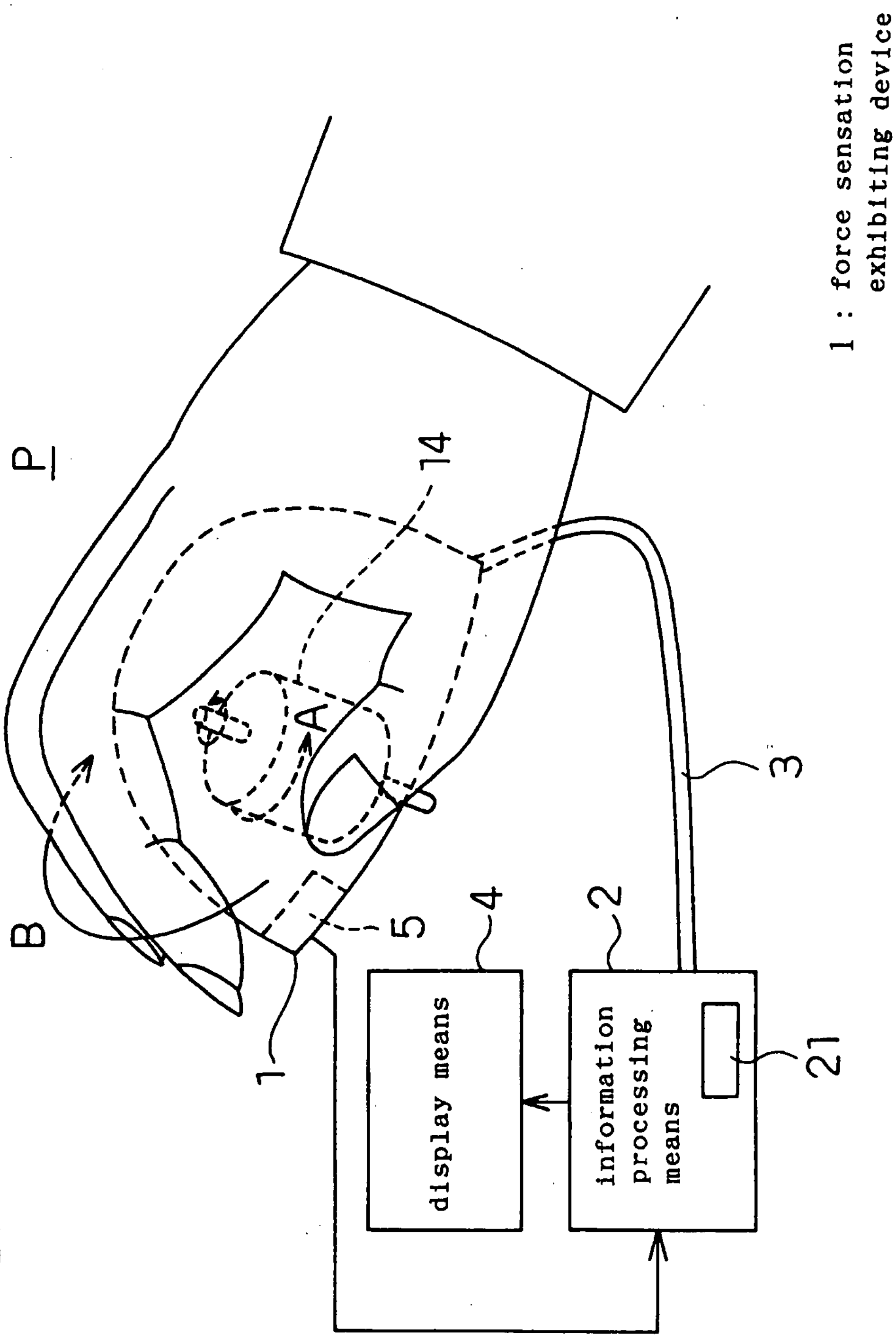

P
14
A
B
1
5
4
2
3
21
display means
information processing means
1 : force sensation exhibiting device

Fig. 2

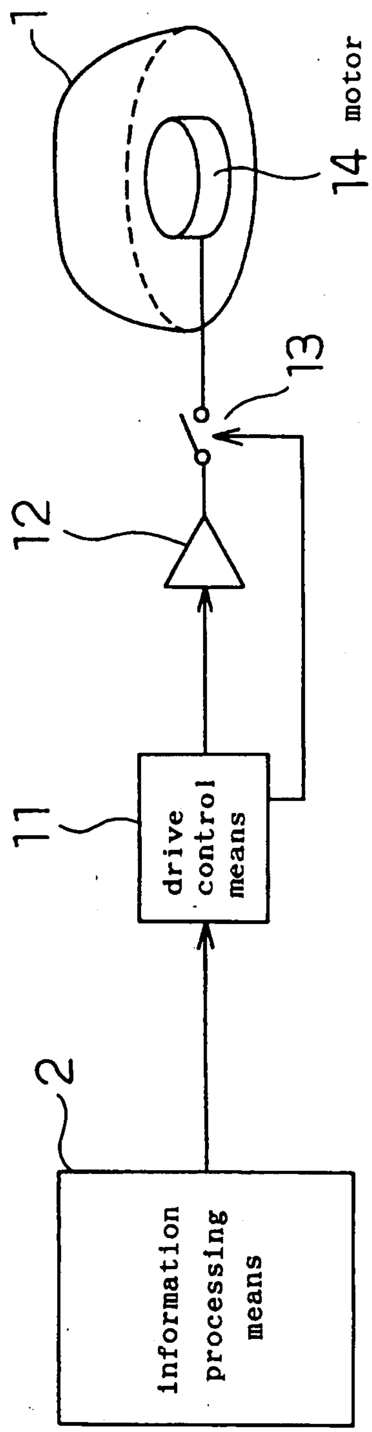

1
14 motor
13
12
11
drive control means
2
information processing means

Fig. 3

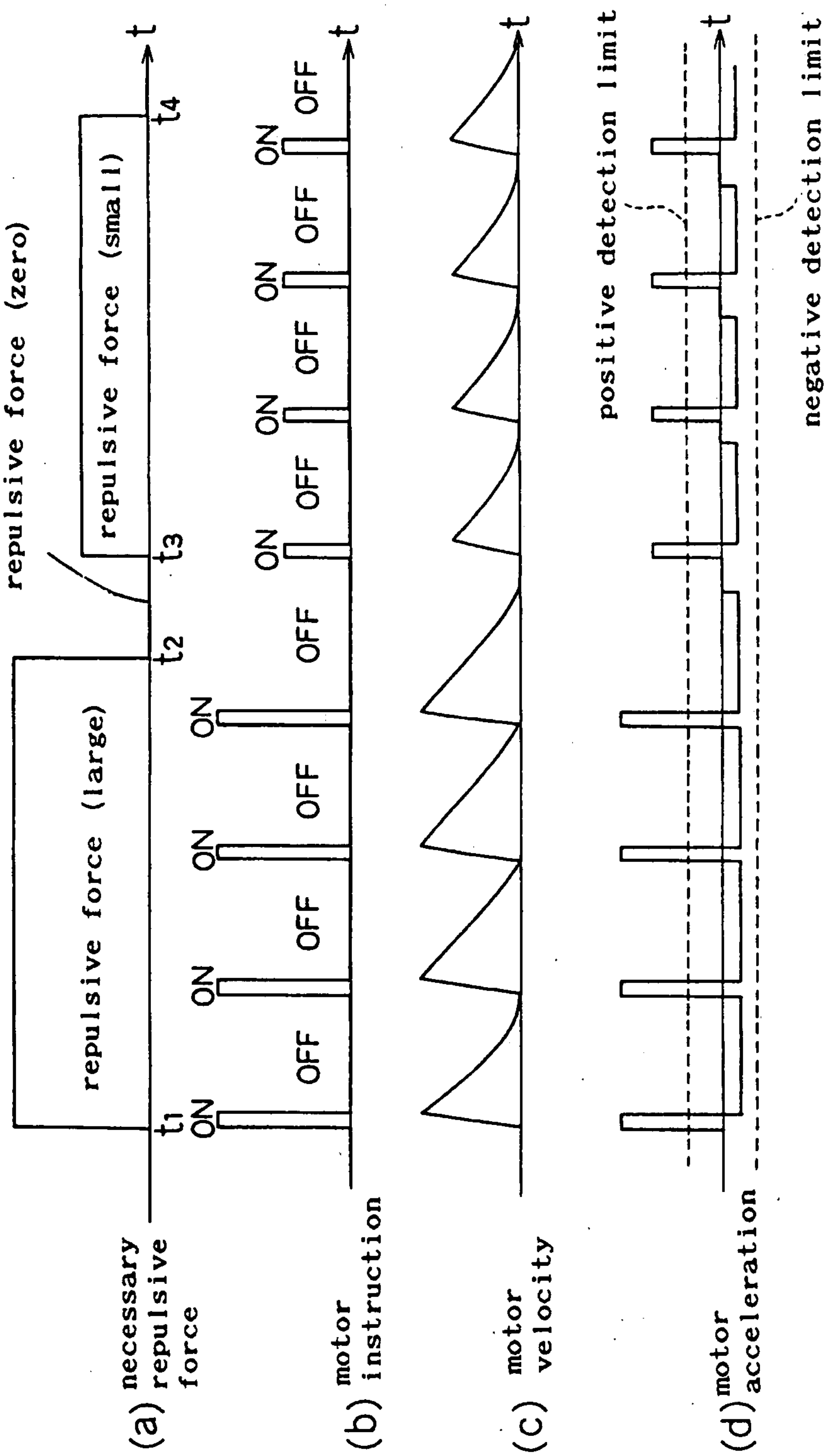

(a) necessary repulsive force
repulsive force (large)
repulsive force (zero)
repulsive force (small)
t1
t2
t3
t4
t
(b) motor instruction
ON
OFF
(c) motor velocity
(d) motor acceleration
positive detection limit
negative detection limit

Fig. 4

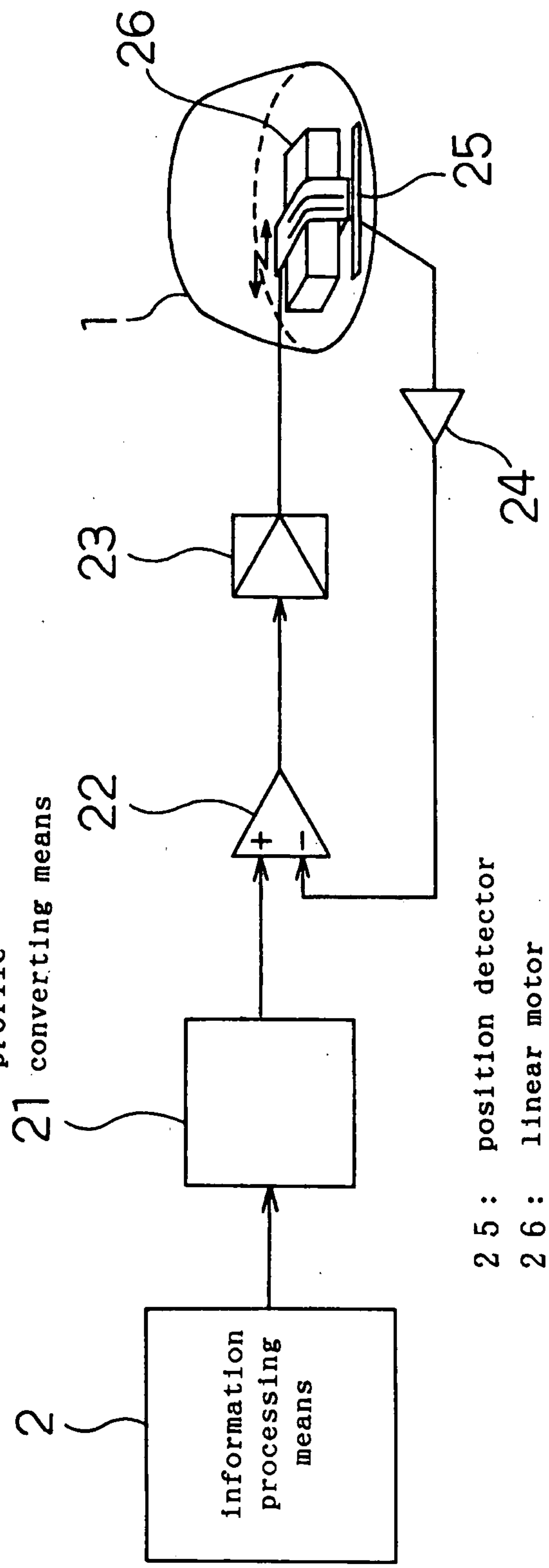

2
information processing means
21
profile converting means
22
23
24
1
26
25
25 : position detector
26 : linear motor

Fig. 5

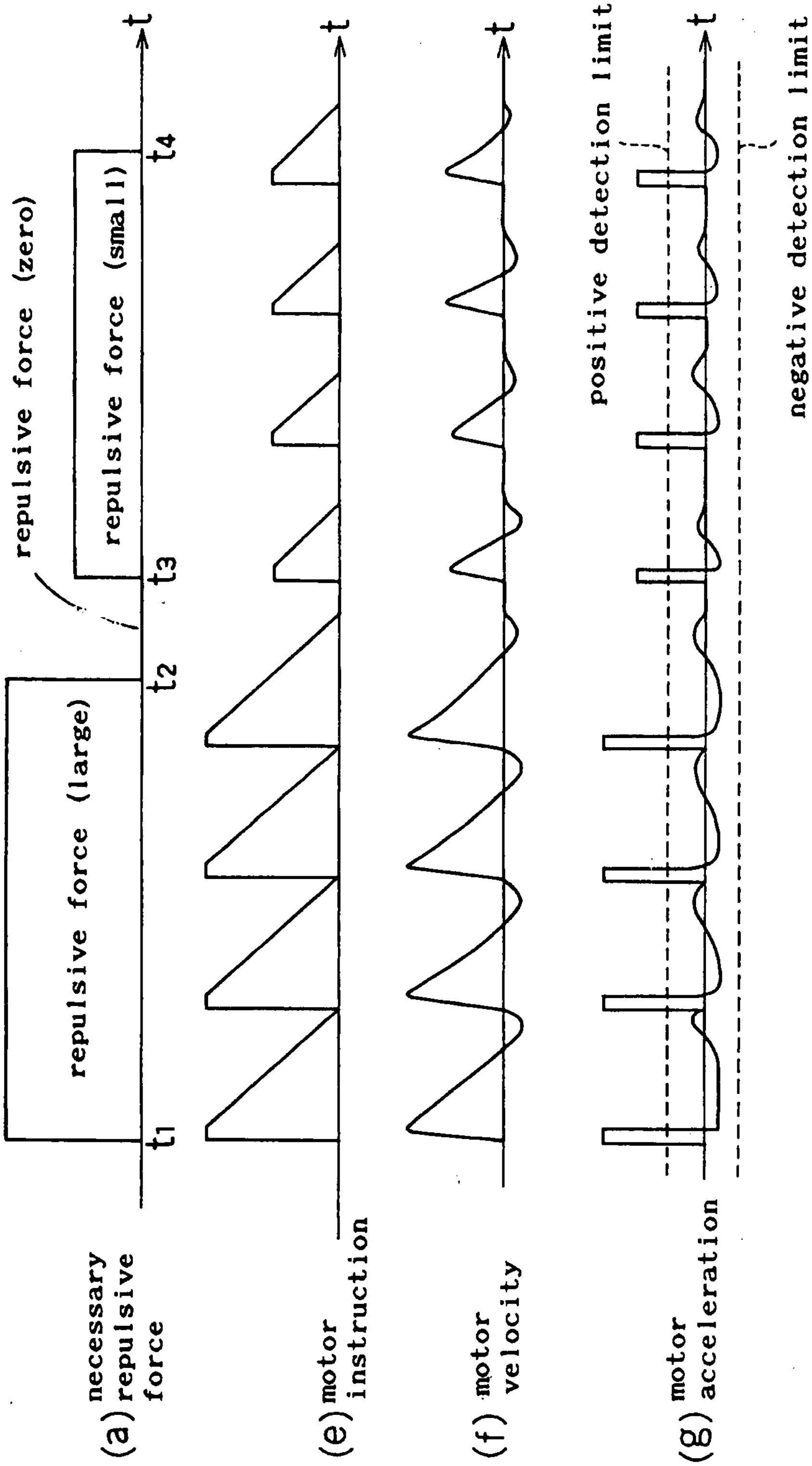
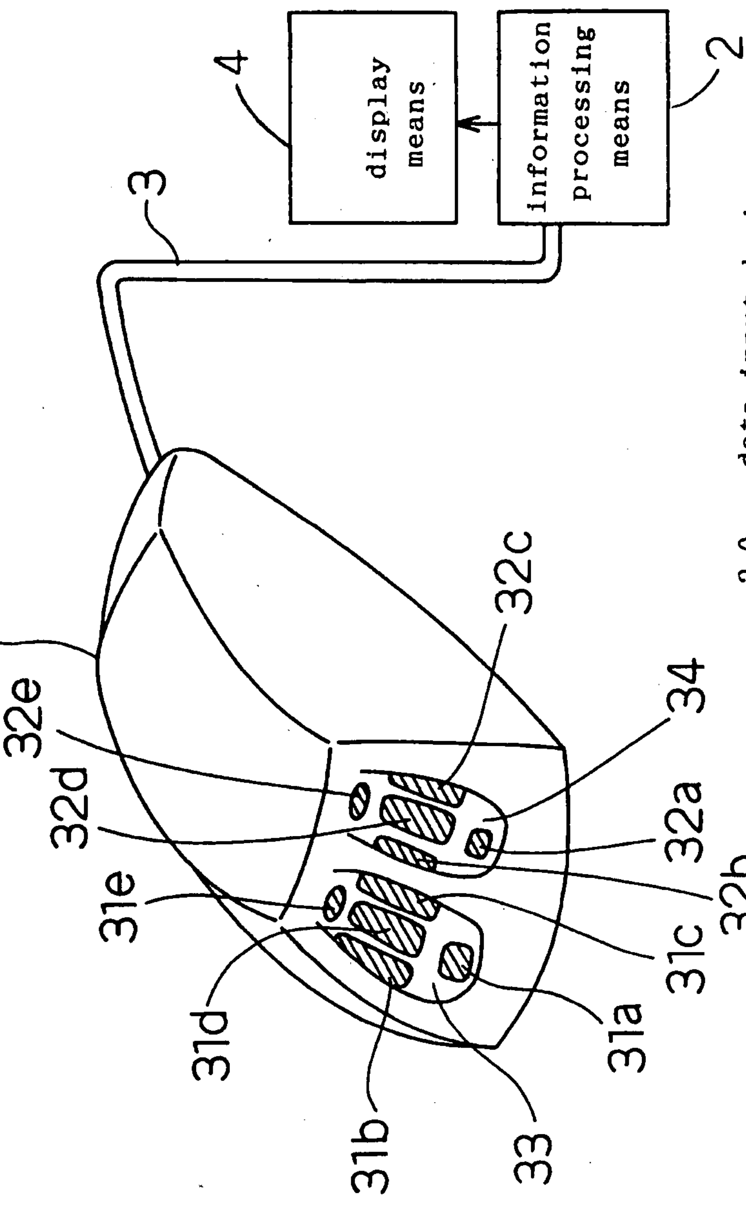

(a) necessary repulsive force
(e) motor instruction
(f) motor velocity
(g) motor acceleration
repulsive force (large)
repulsive force (zero)
repulsive force (small)
t1
t2
t3
t4
t
positive detection limit
negative detection limit

Fig. 6



30: data input device

31a～31e: pressure sensors

32a～32e: pressure sensors

Fig. 7

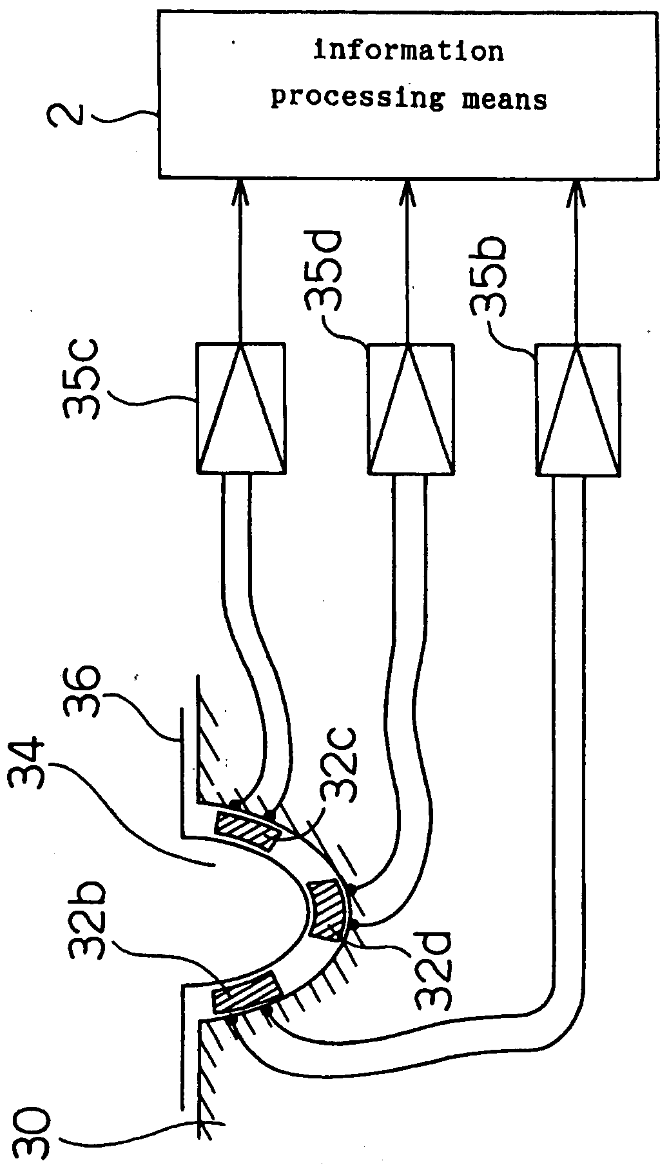

information processing means
2
35c
35d
35b
36
34
32c
32b
32d
30

Fig. 8

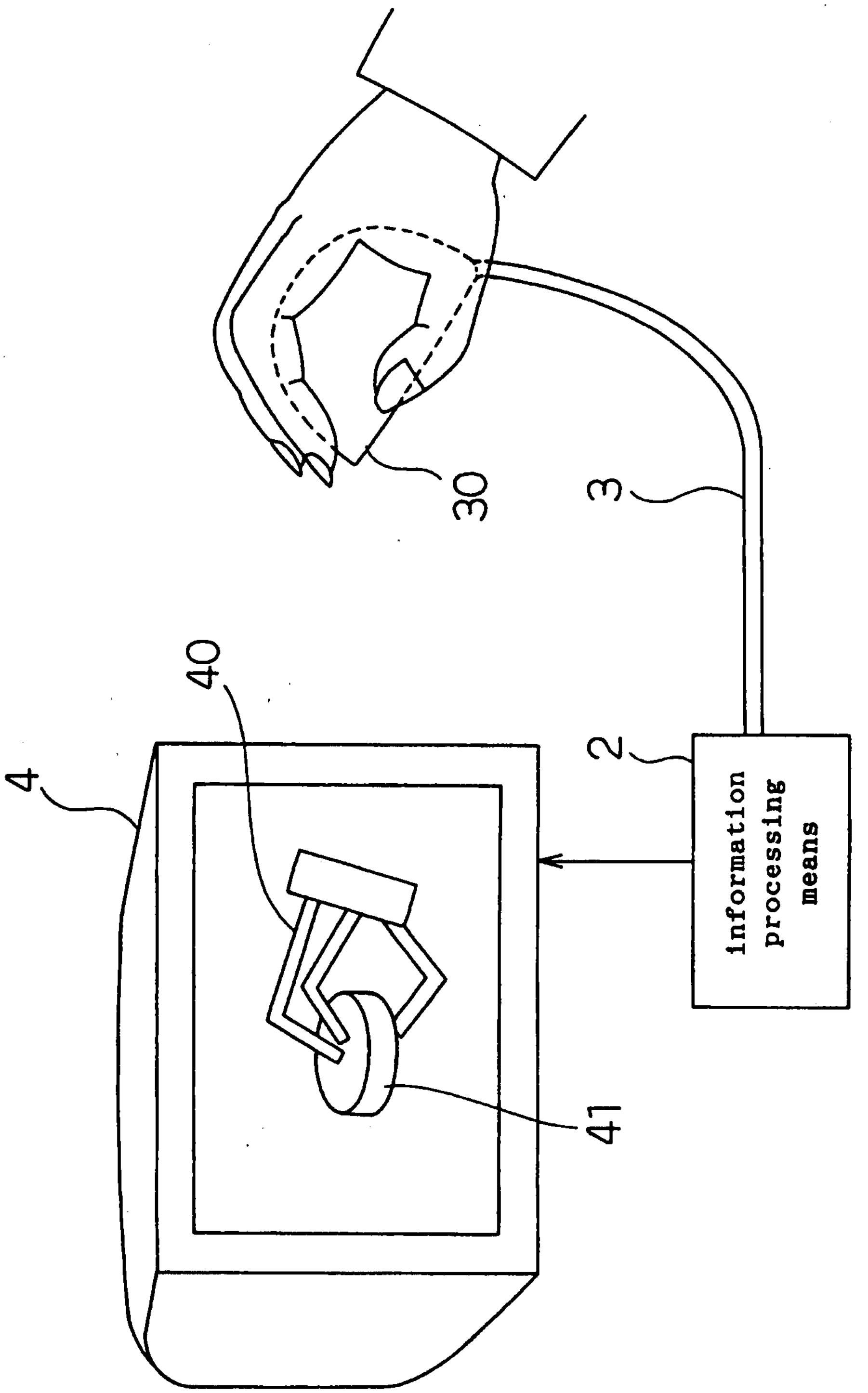
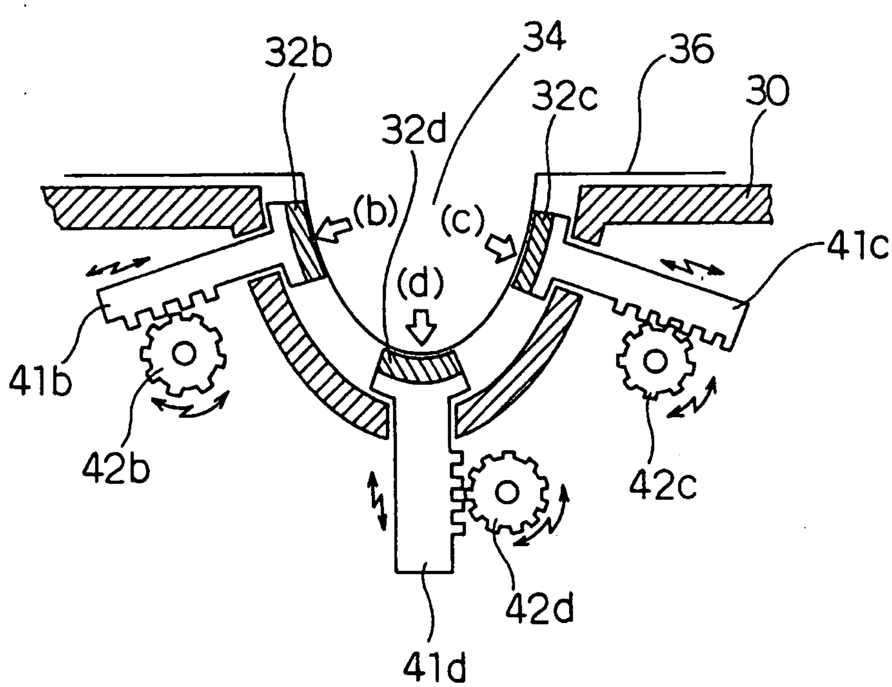


Fig. 9



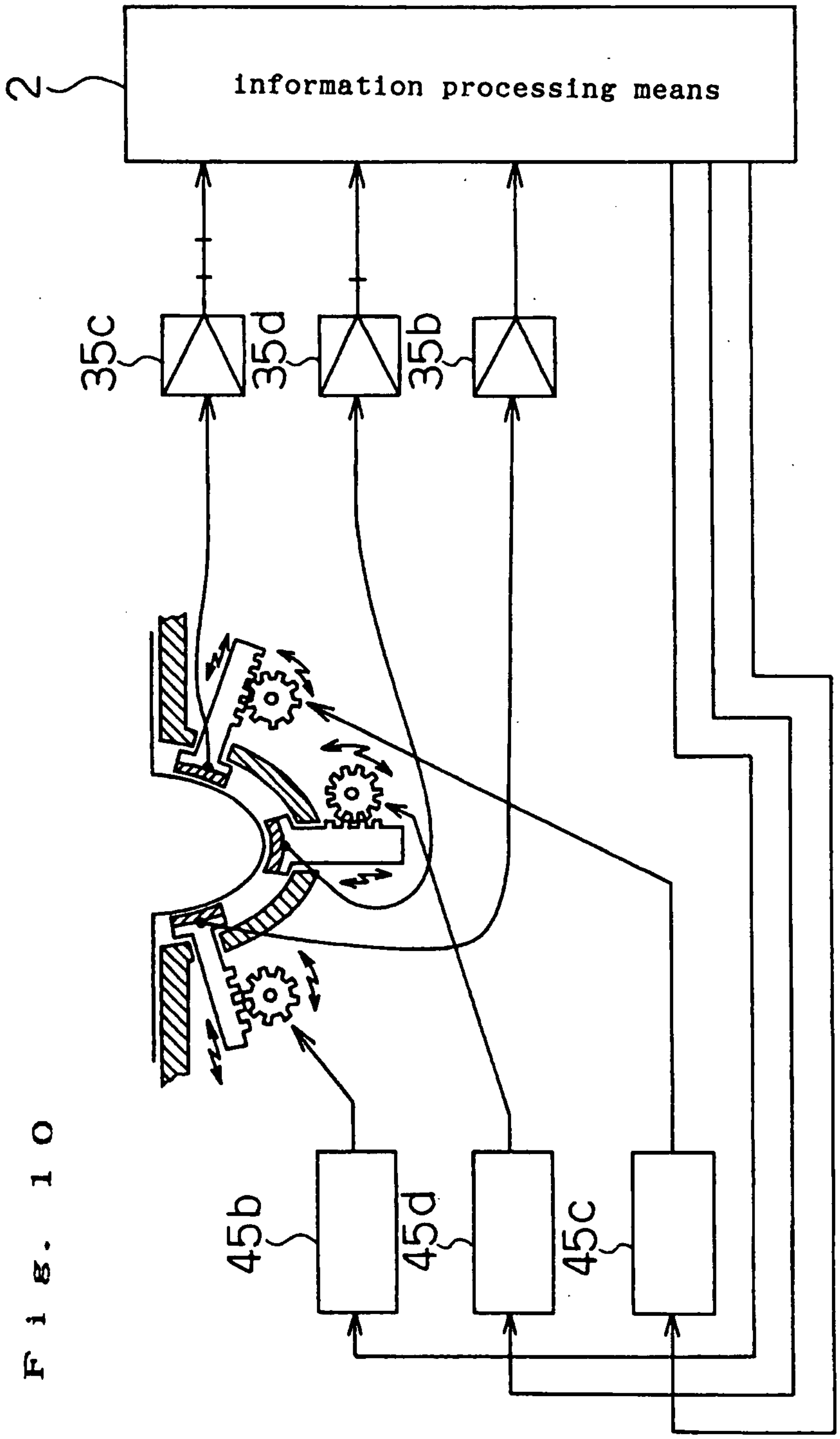
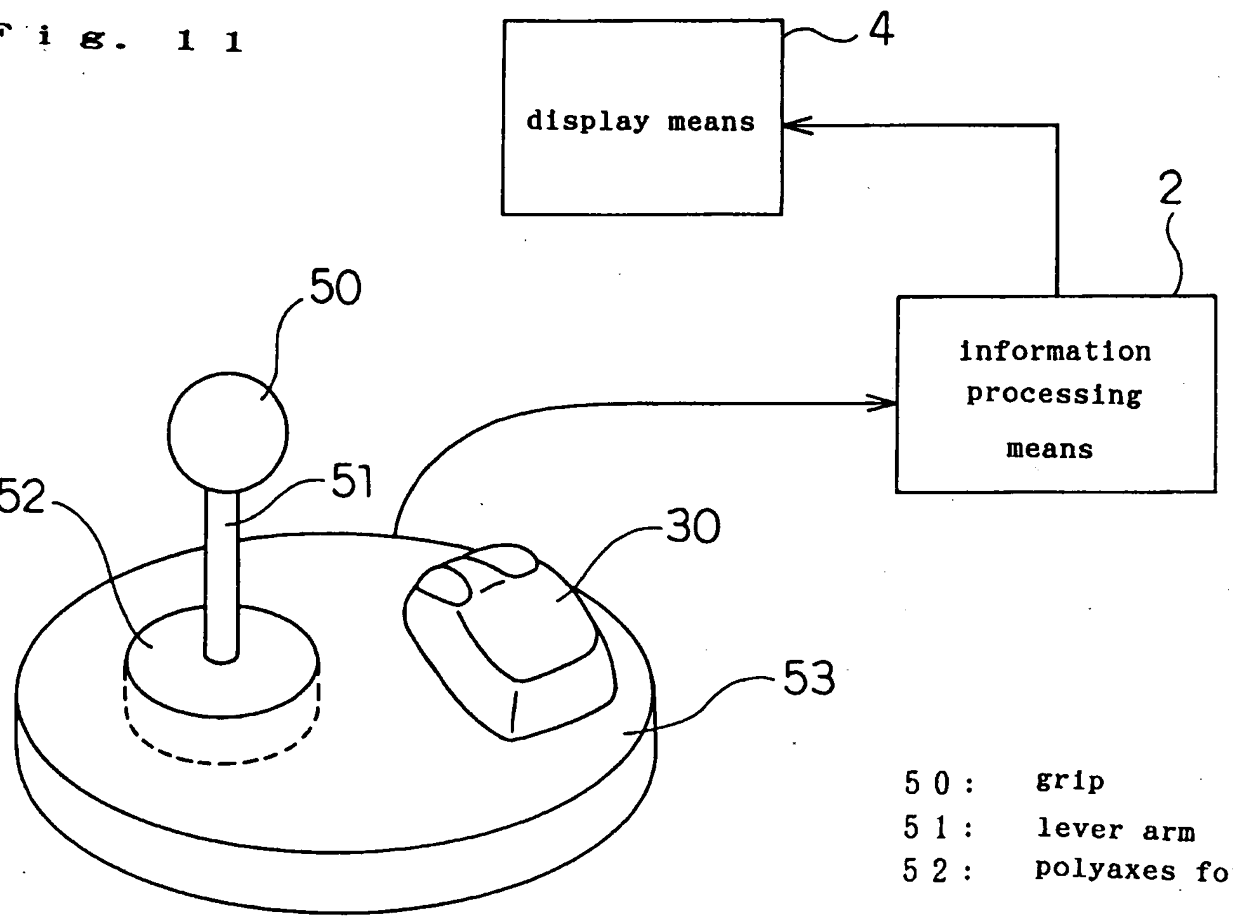


Fig. 10

45b, 45c, 45d : drive control means

Fig. 11



50 : grip
51 : lever arm
52 : polyaxes force sensor

Fig. 12

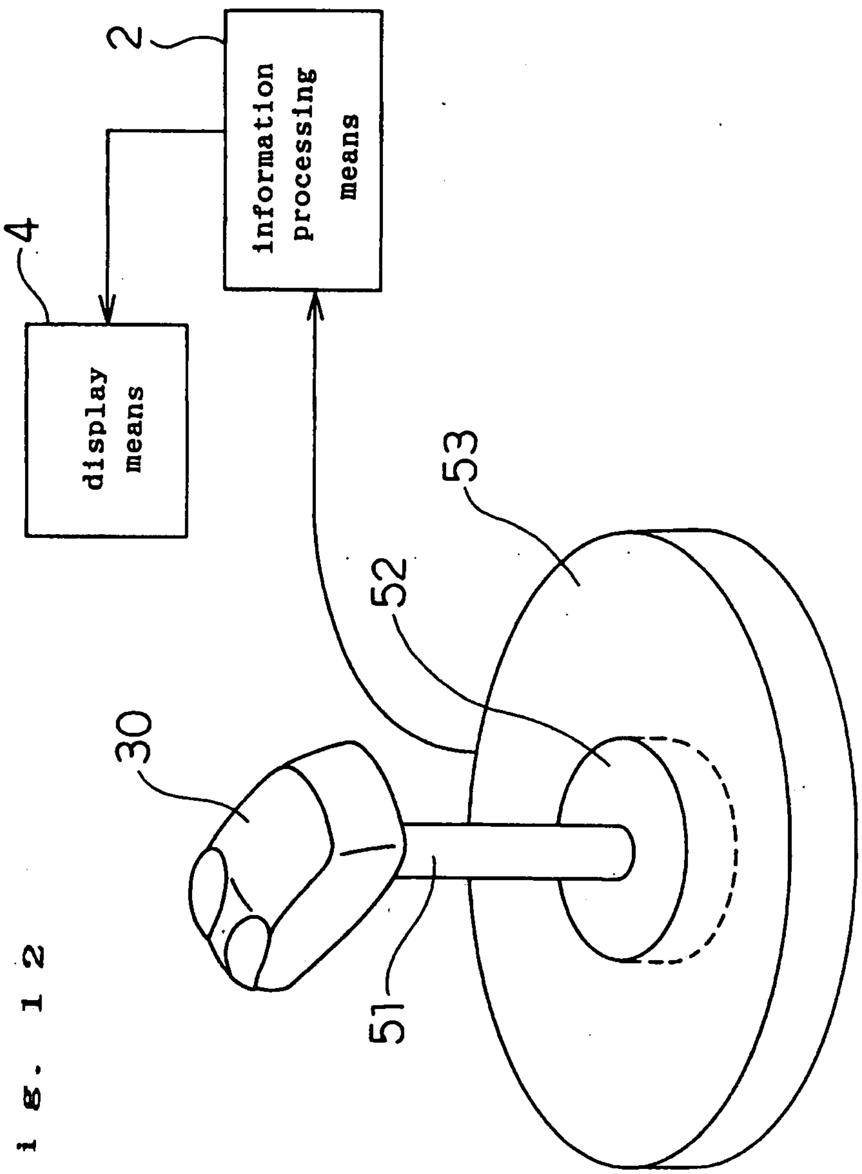
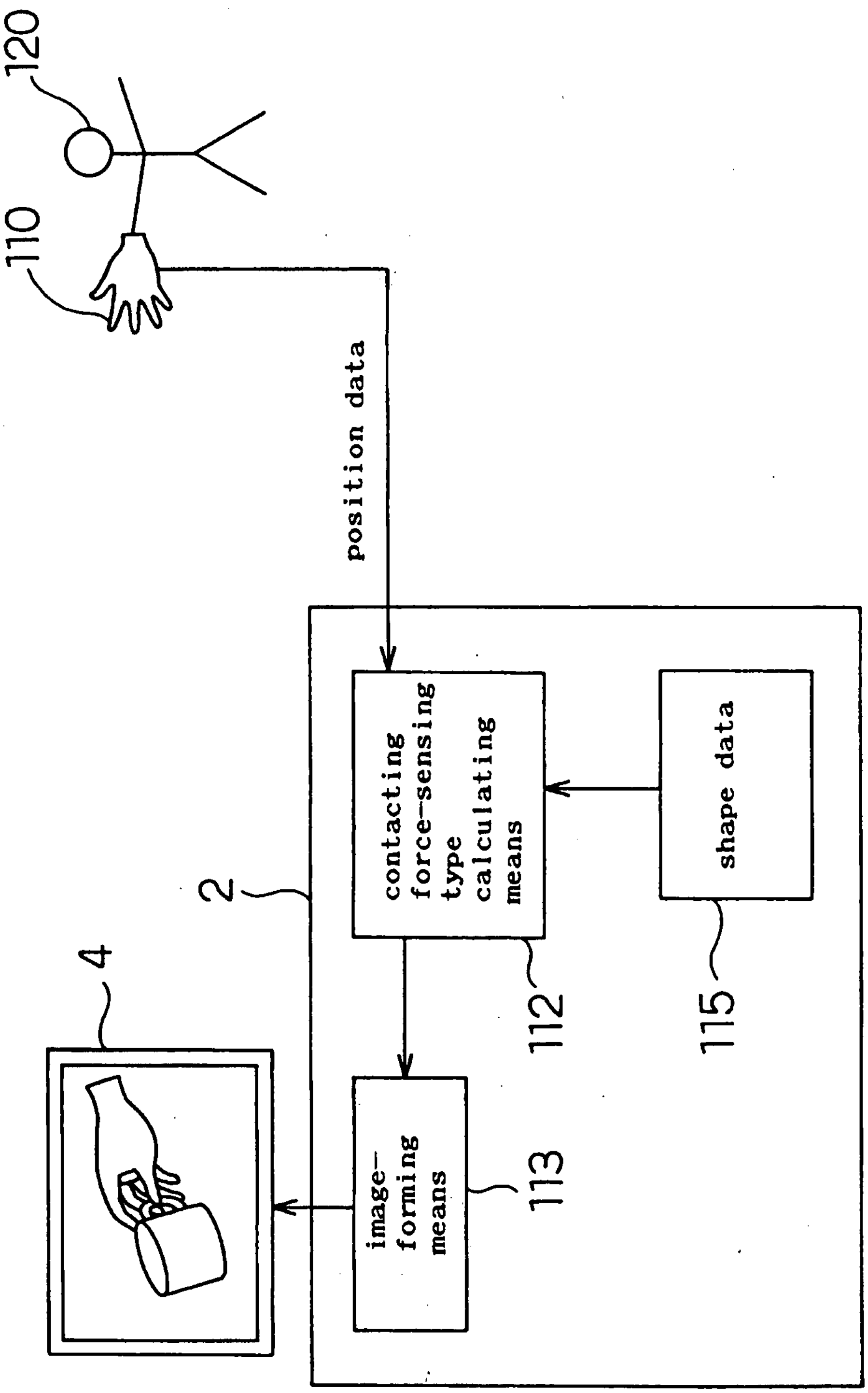


Fig. 13


120
110
position data
2
contacting force-sensing type calculating means
shape data
112
115
4
image-forming means
113

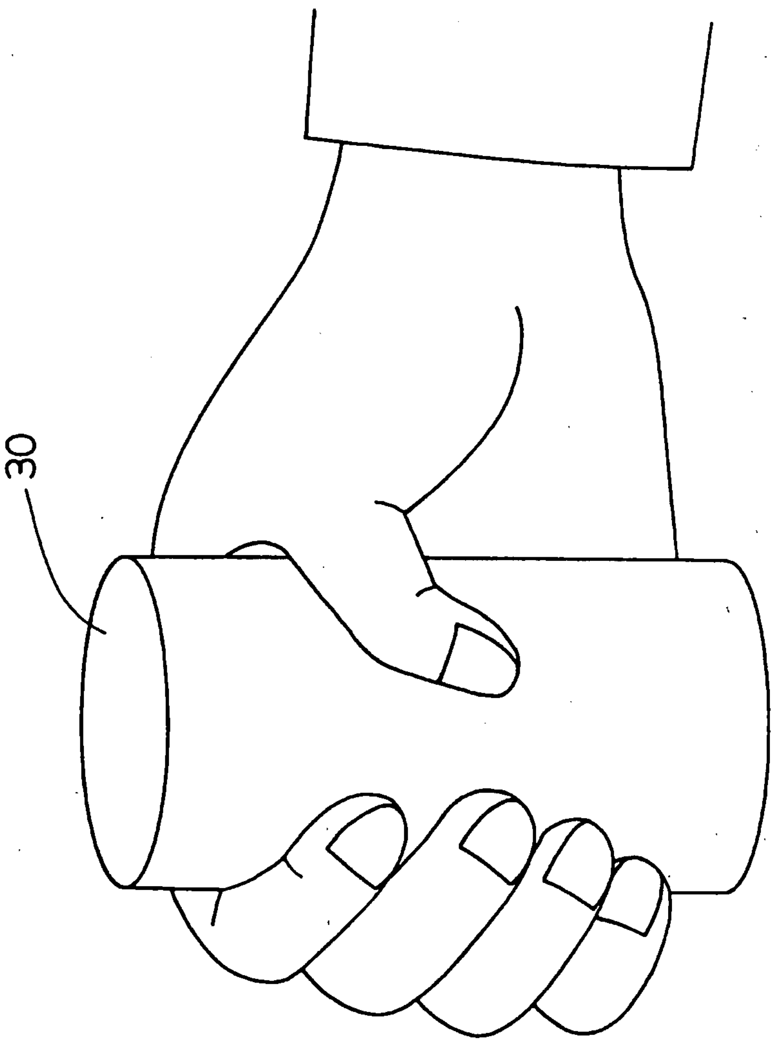


Fig. 14

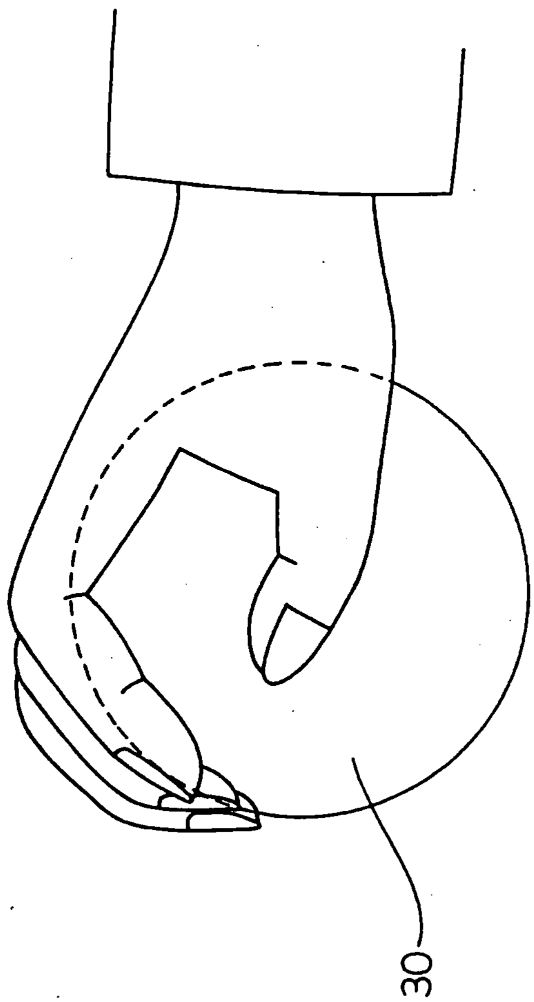


Fig. 15

Fig. 16

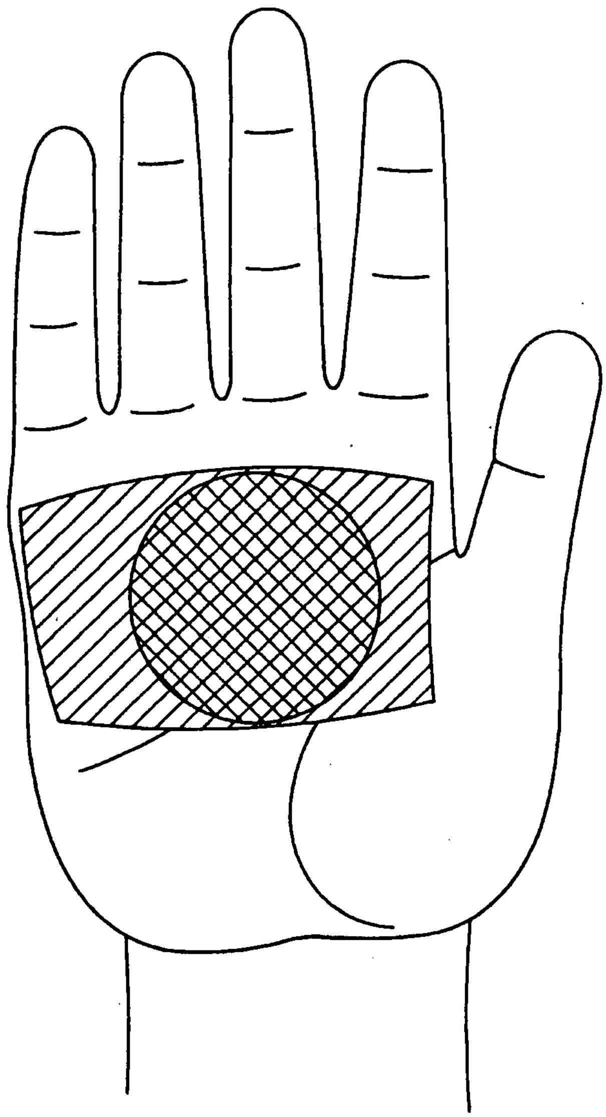
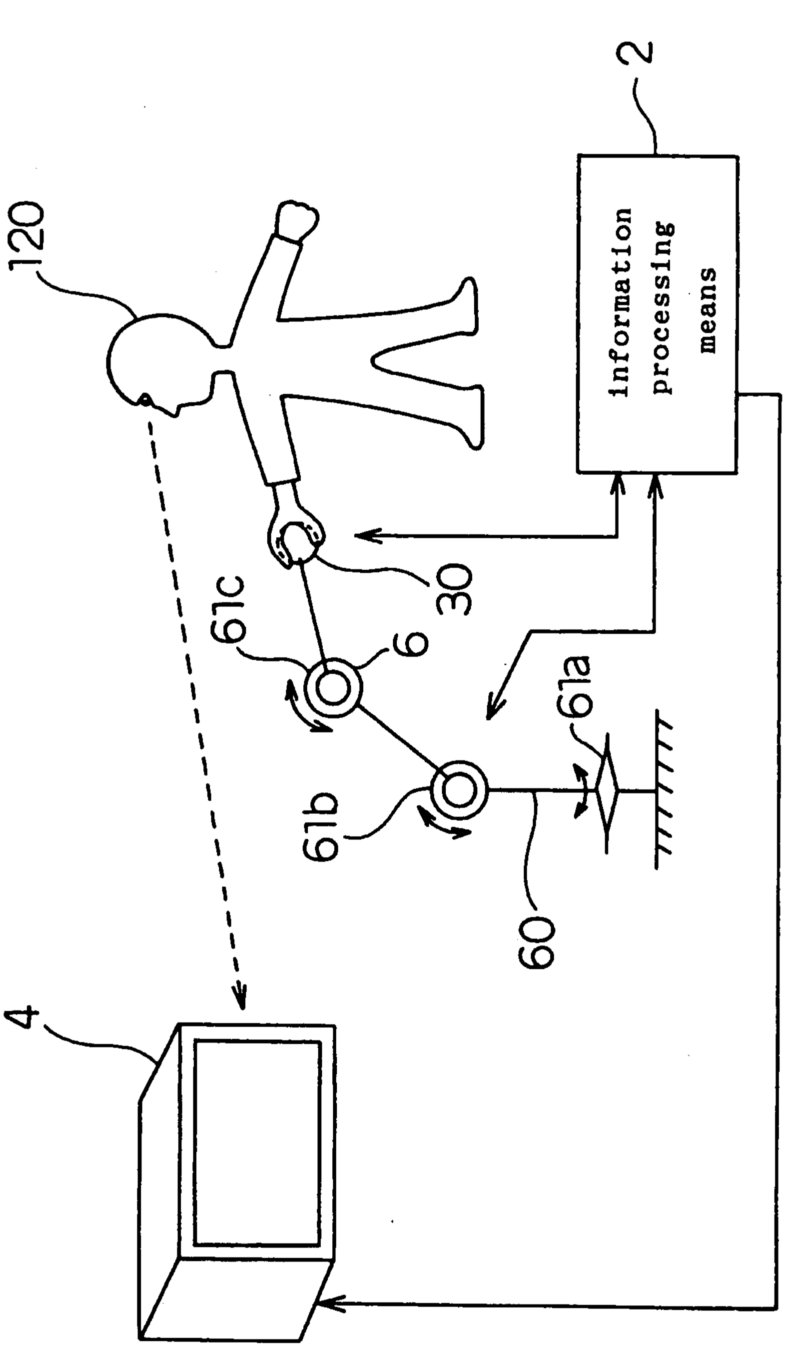


Fig. 17



60: manipulator

Fig. 18

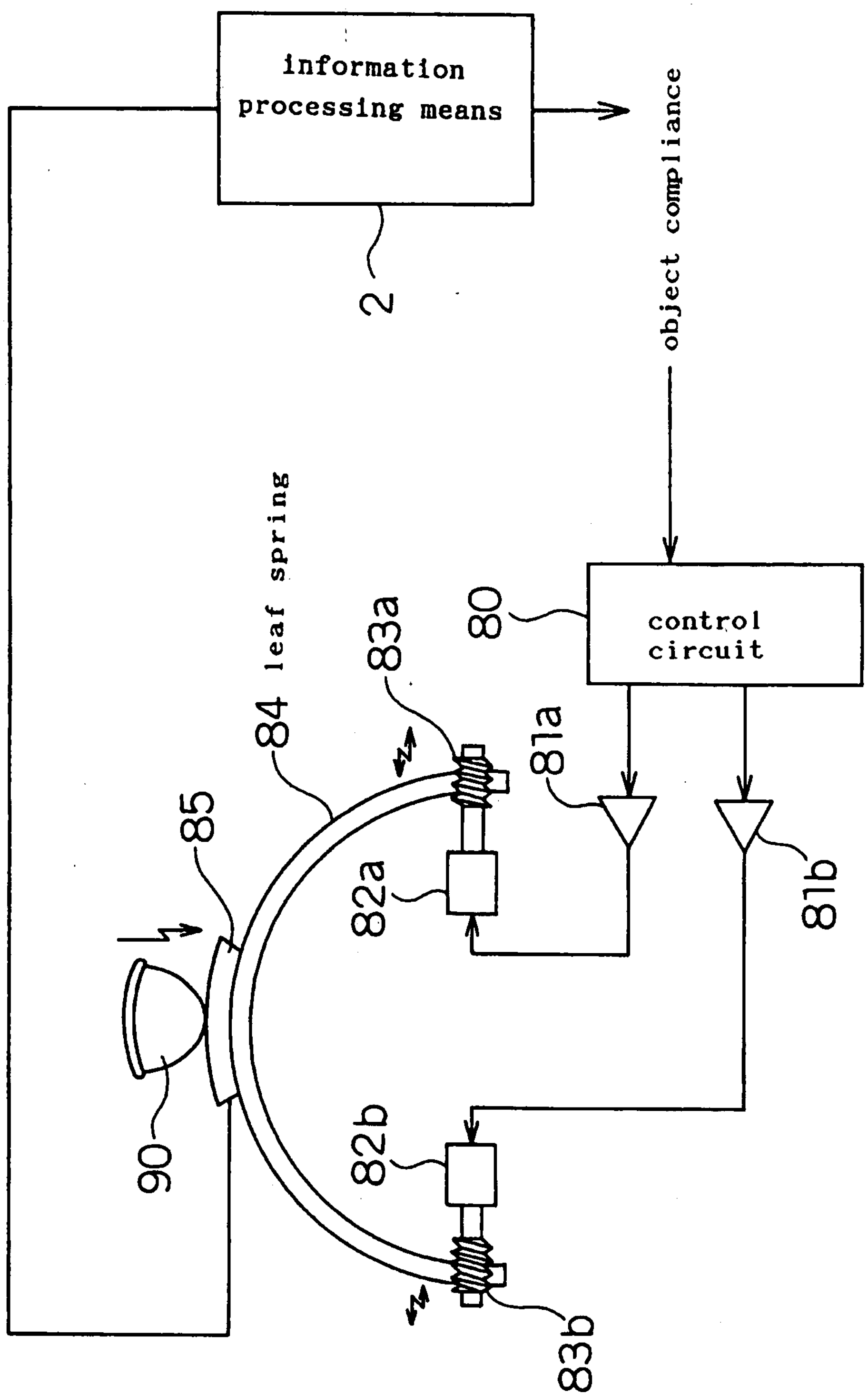

information
processing means
object compliance
2
leaf spring
84
83a
80
control
circuit
81a
85
82a
81b
90
82b
83b

Fig. 19

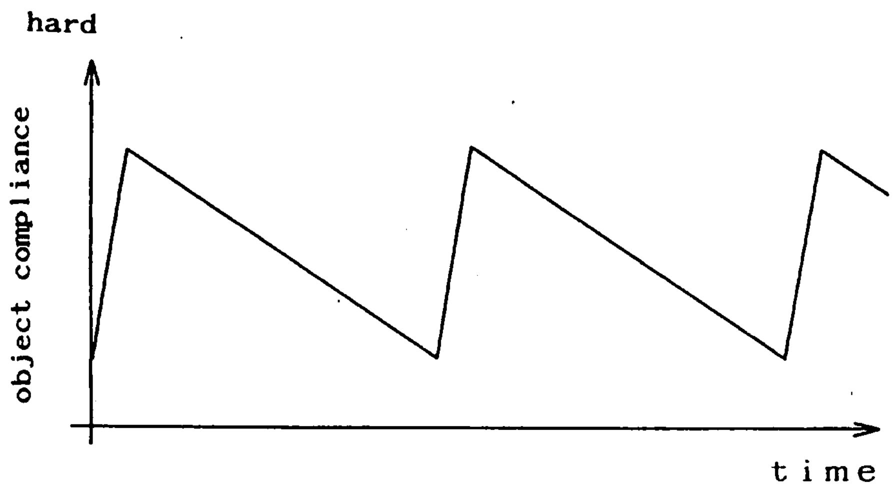


Fig. 20

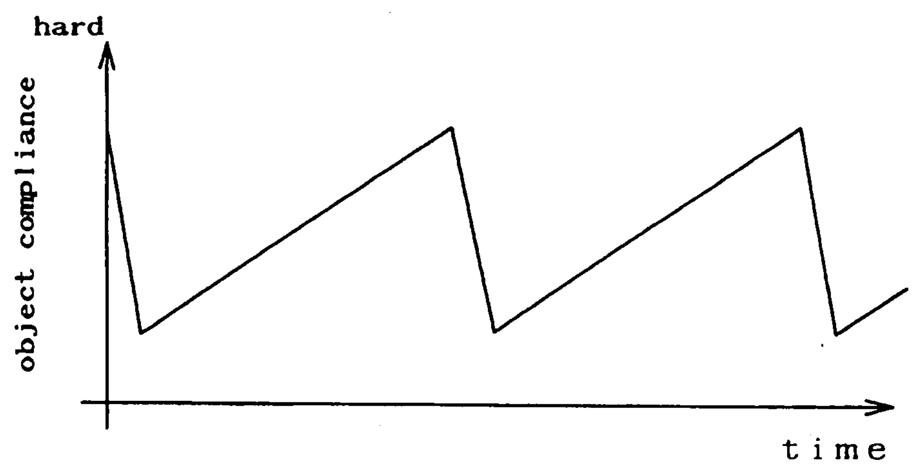
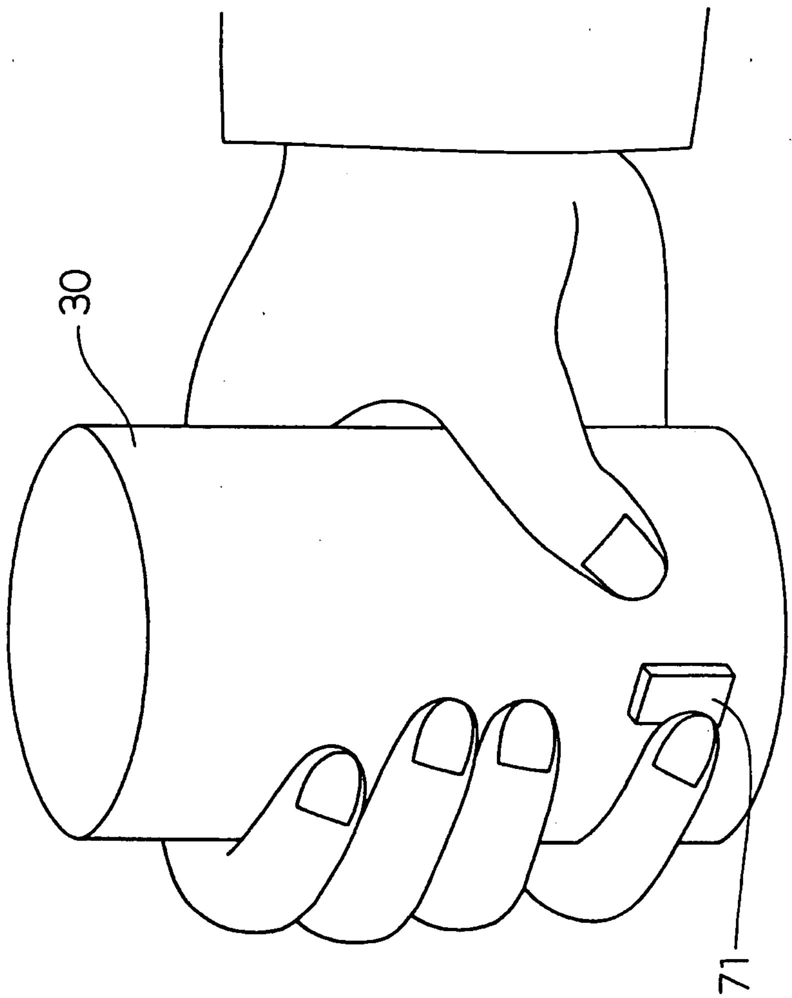


Fig. 21



71: switch

Fig. 22

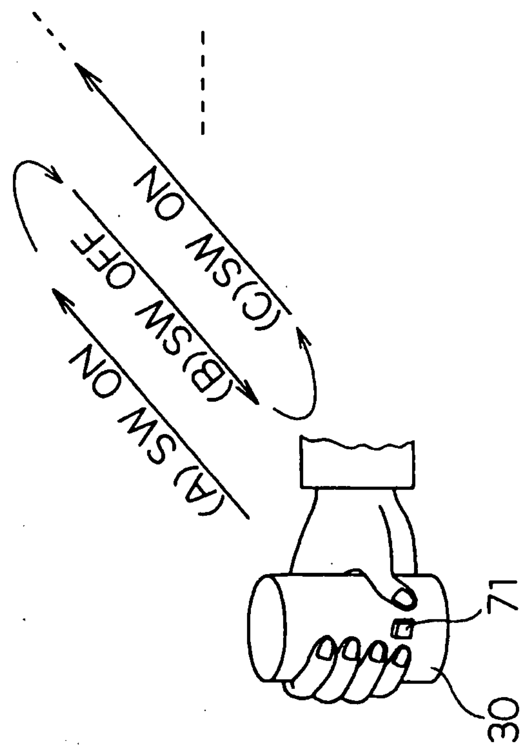


Fig. 23

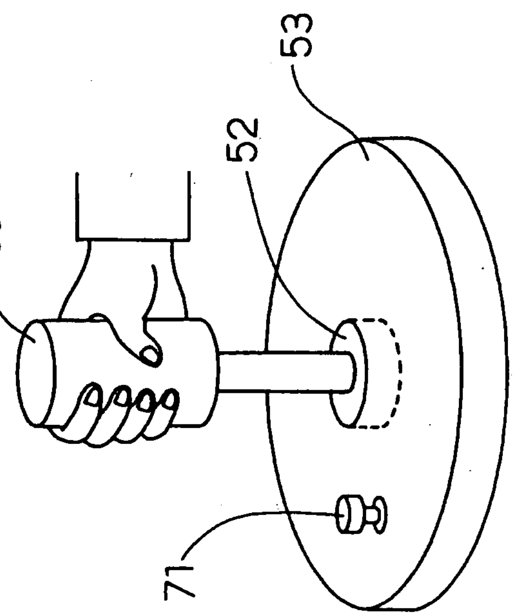
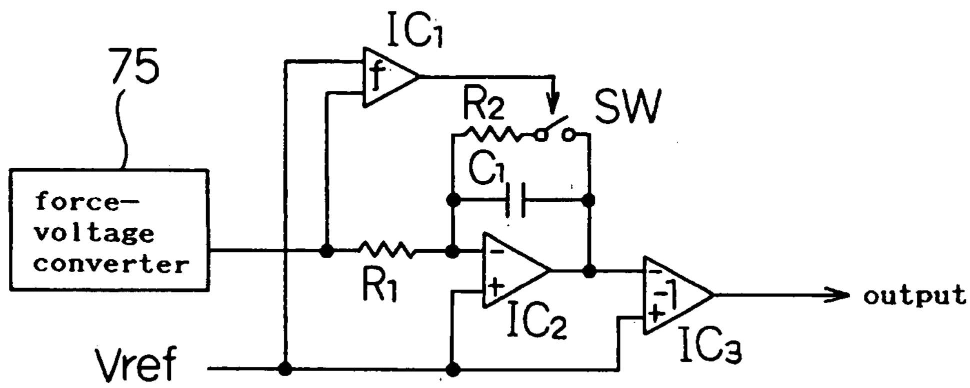
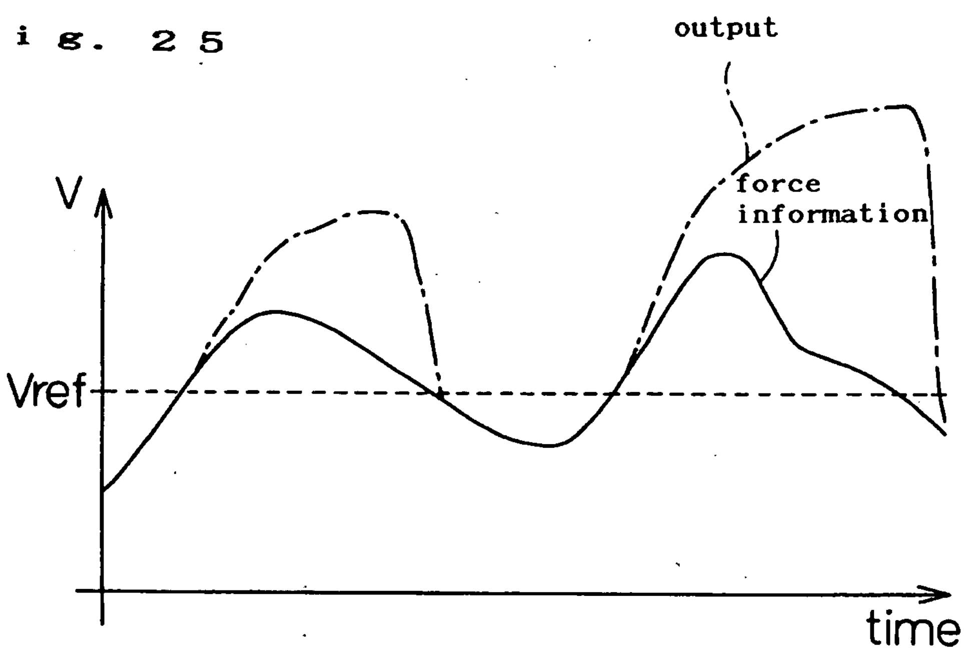


Fig. 24



75
force-
voltage
converter
IC1
f
R2
SW
C1
R1
IC2
-1
IC3
output
Vref

Fig. 25



output
force
information
V
Vref
time

Fig. 26

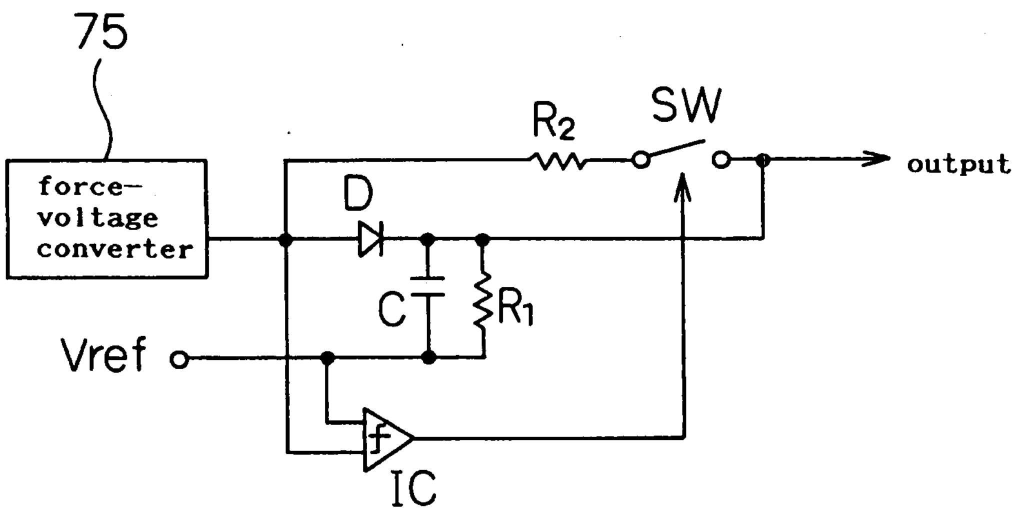
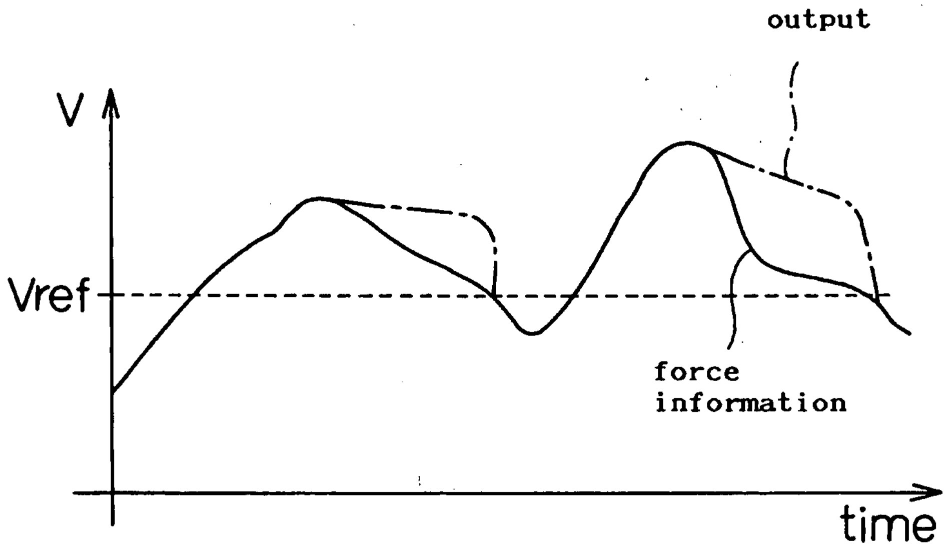

75
force-
voltage
converter
D
R2
SW
output
C
R1
Vref
f
IC

Fig. 27


output
V
Vref
force
information
time

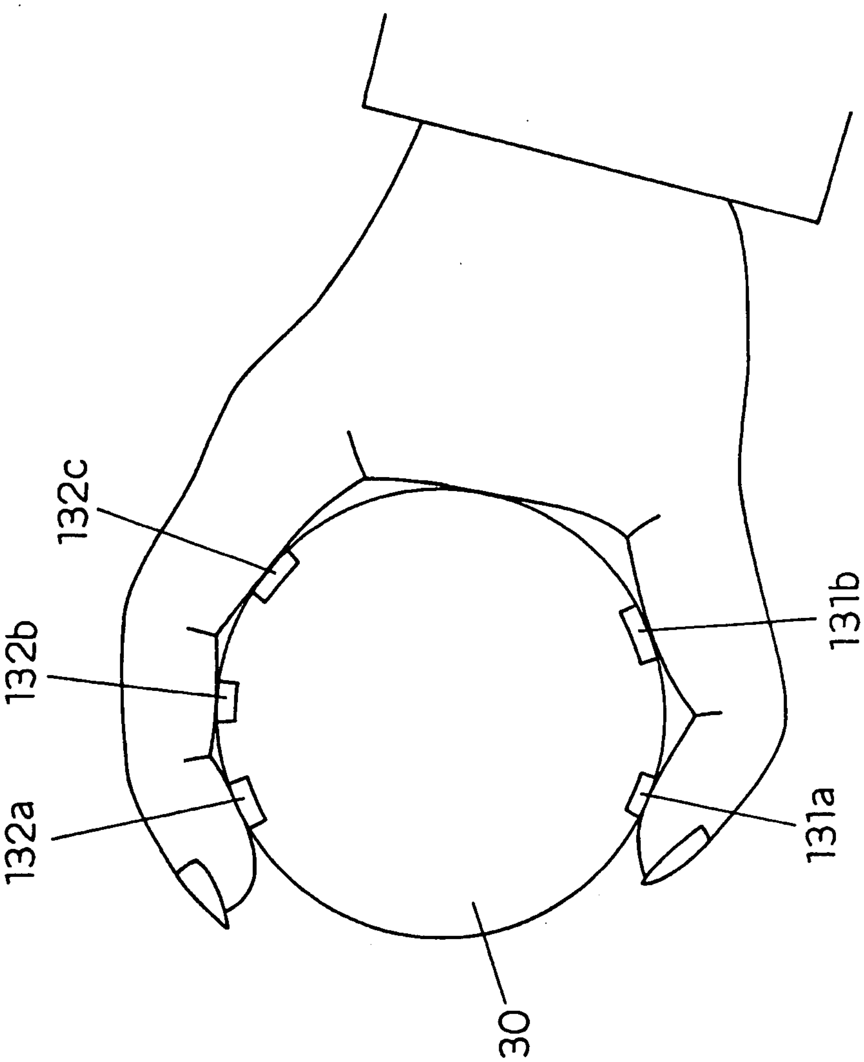


Fig. 28

Fig. 29

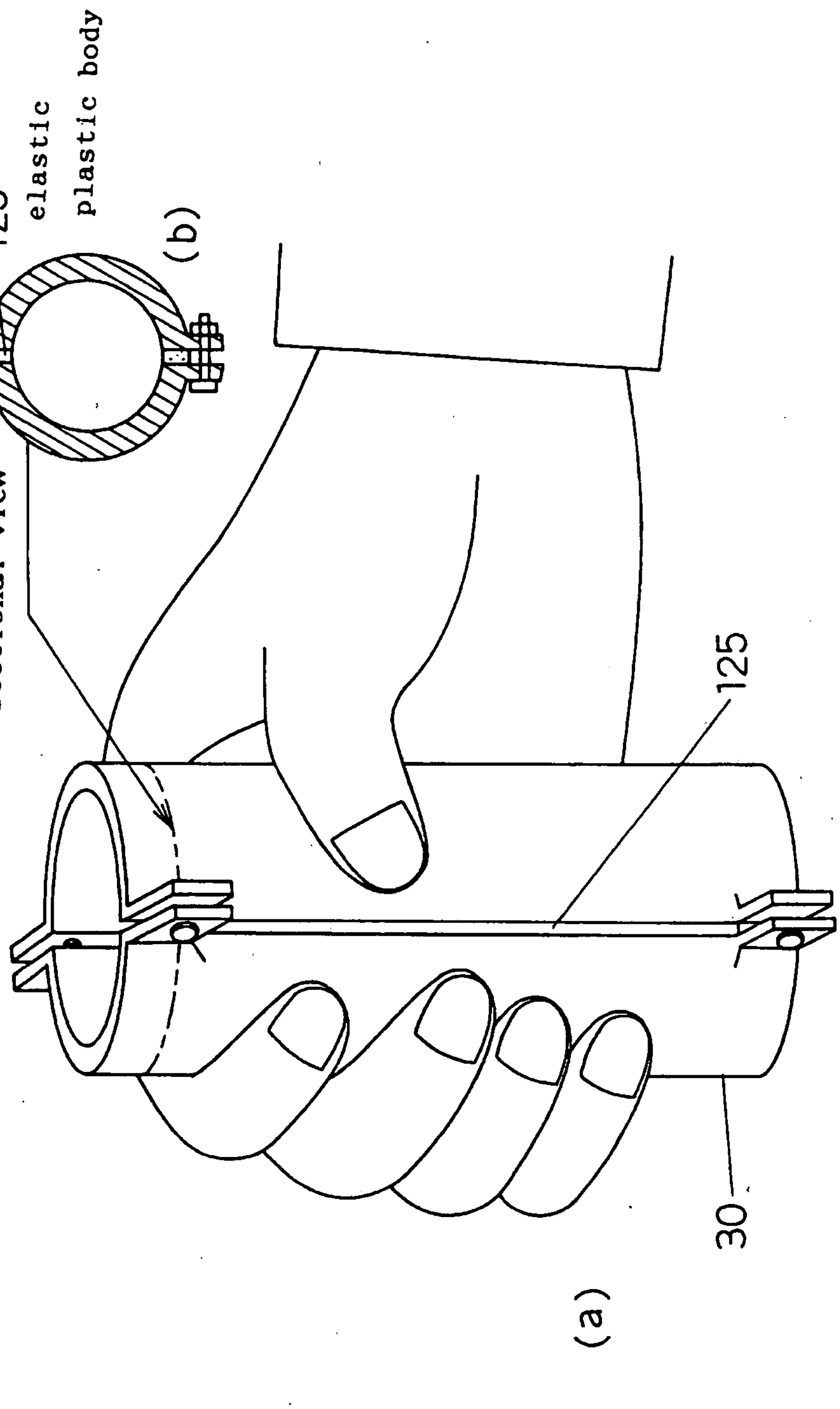
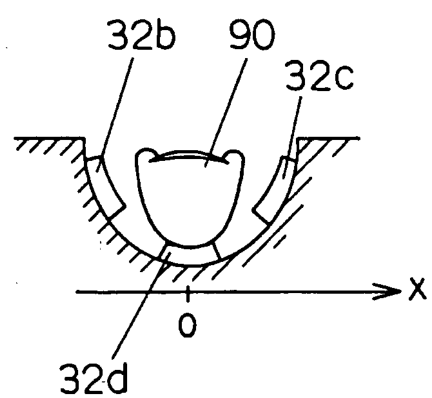
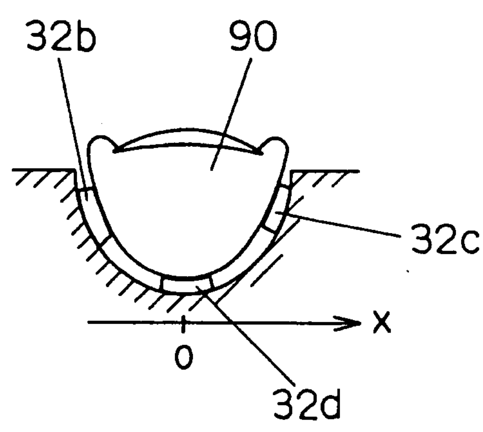


Fig. 30



(a)



(b)

Fig. 31

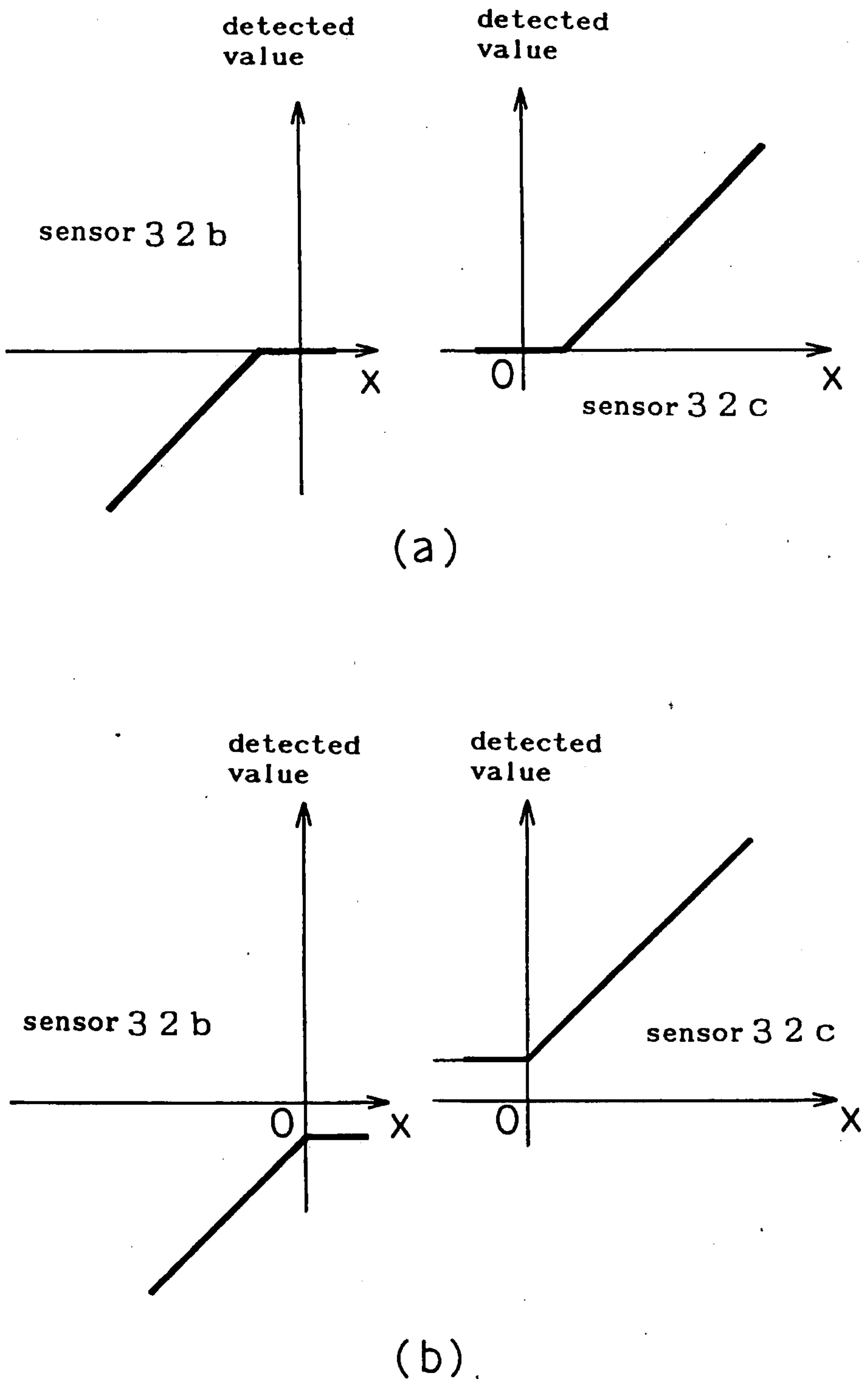

detected value
detected value
sensor 3 2 b
X
0
X
sensor 3 2 c
(a)
detected value
detected value
sensor 3 2 b
sensor 3 2 c
0
X
0
X
(b)

Fig. 32

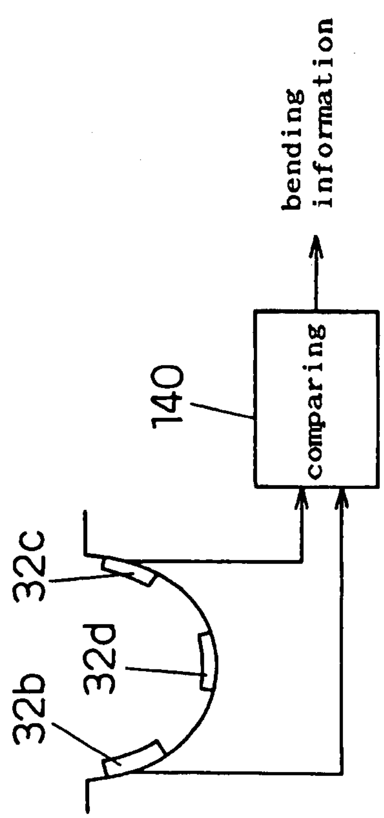

32b
32d
32c
140
comparing
bending information

Fig. 33

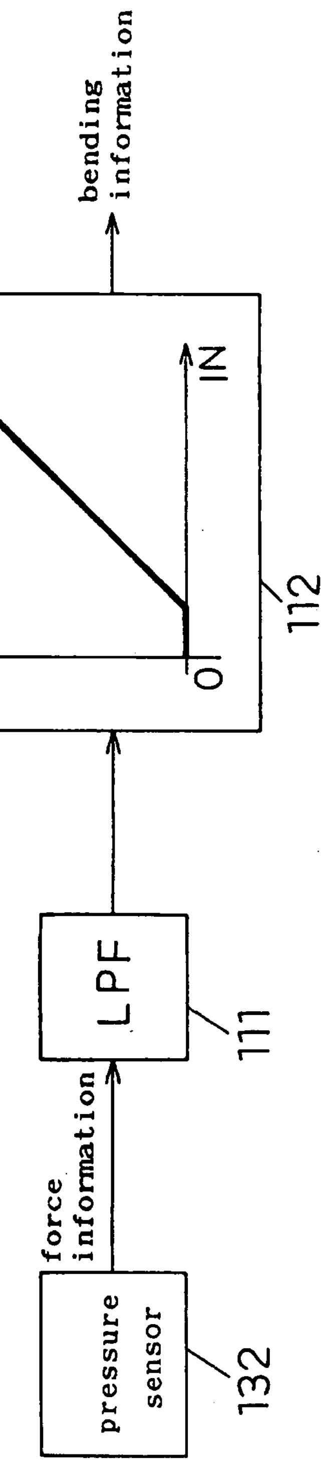

pressure sensor
132
force information
LPF
111
Out
0
IN
112
bending information

Fig. 34

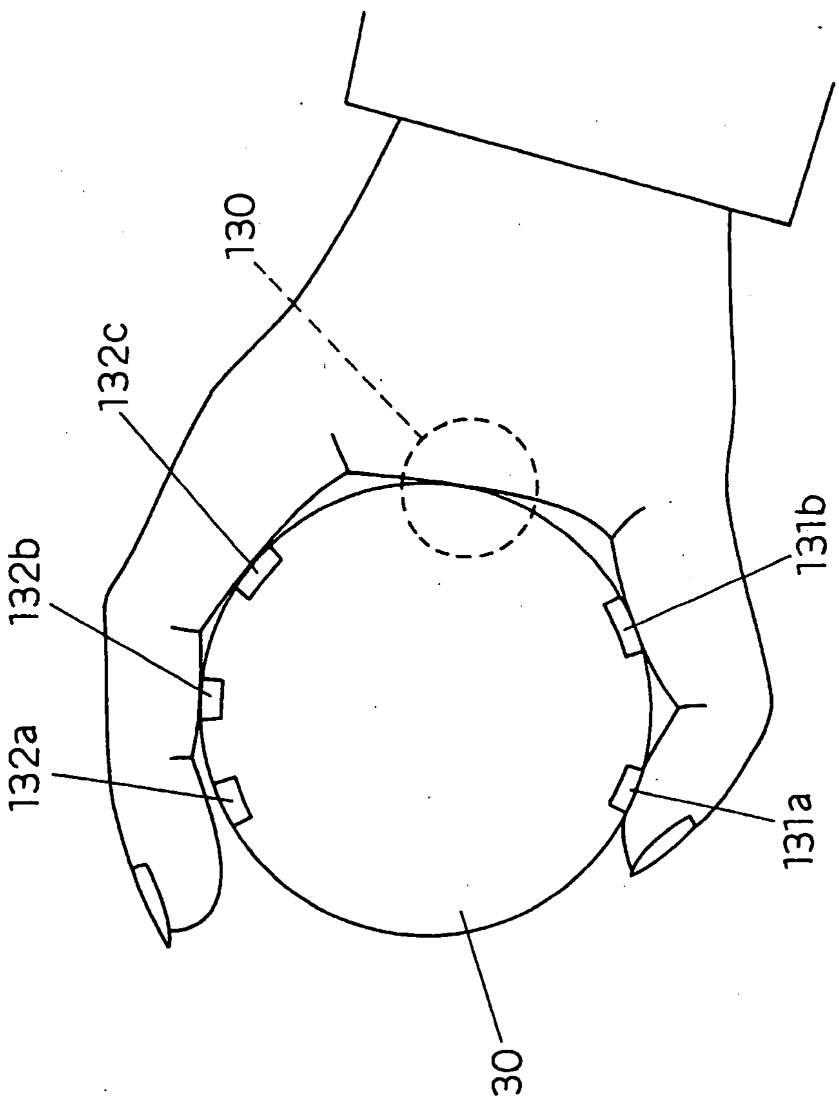


Fig. 35

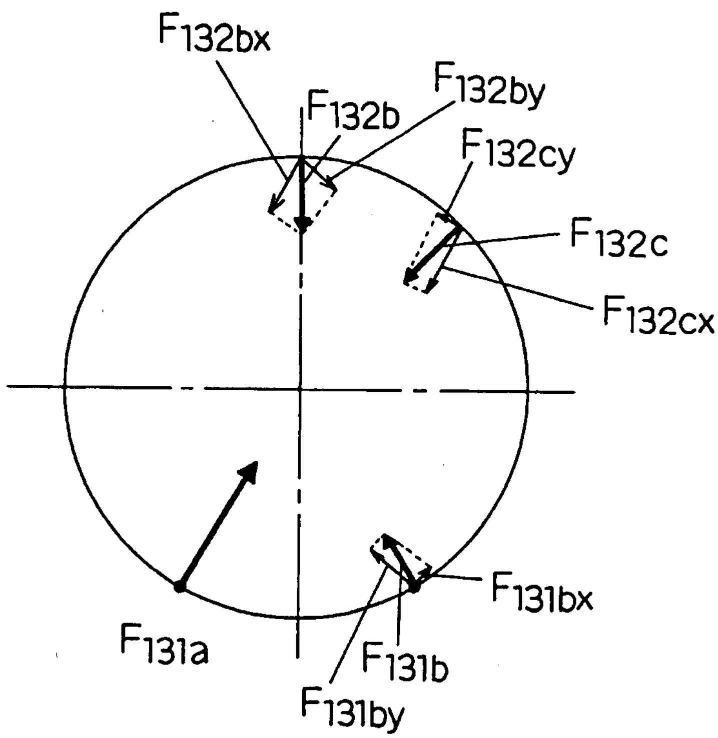

F_{132bx}
F_{132b}
F_{132by}
F_{132cy}
F_{132c}
F_{132cx}
F_{131bx}
F_{131a}
F_{131b}
F_{131by}

Fig. 36

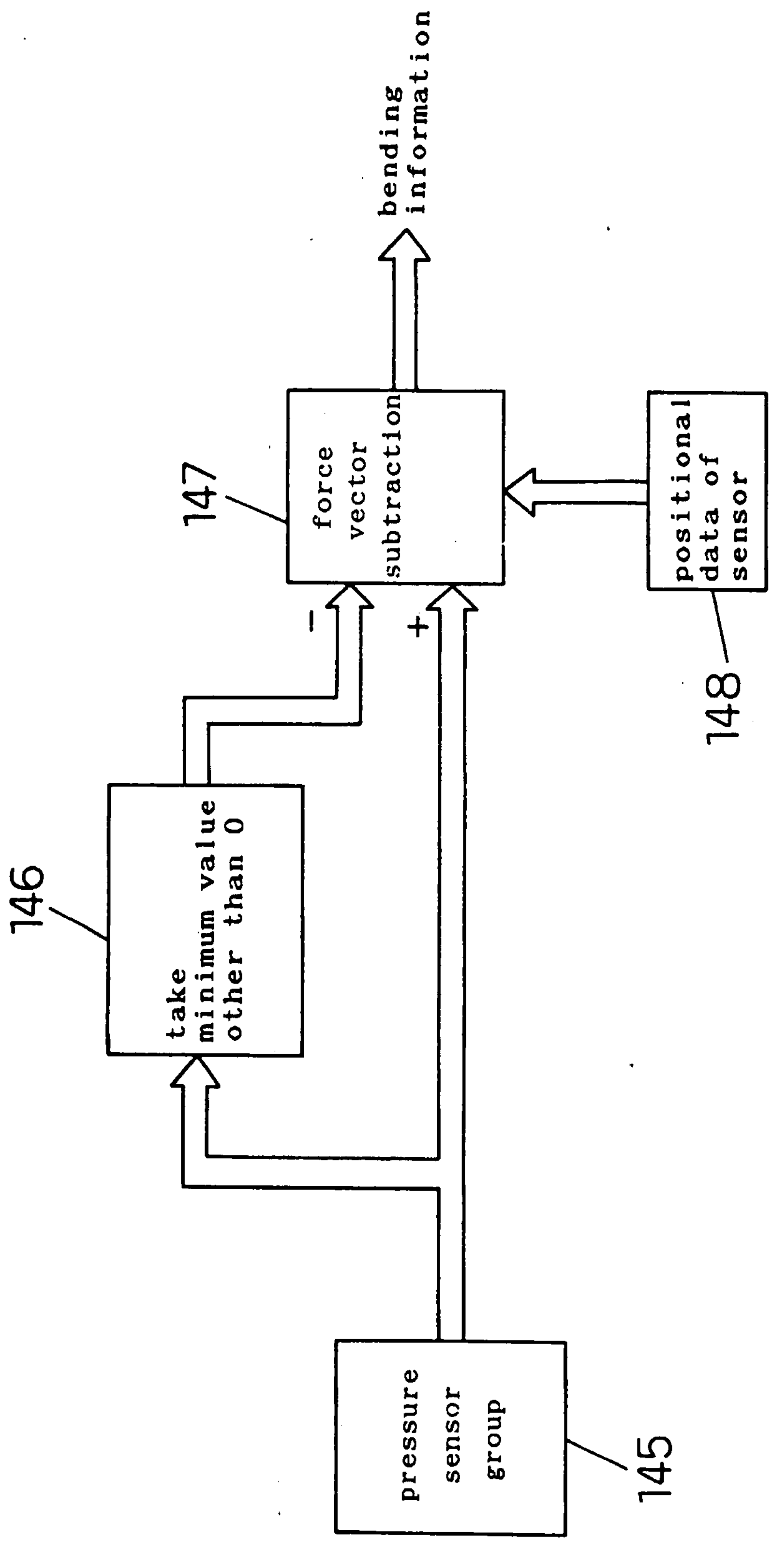

bending information
147
force vector subtraction
positional data of sensor
148
146
take minimum value other than 0
−
+
pressure sensor group
145

Fig. 37

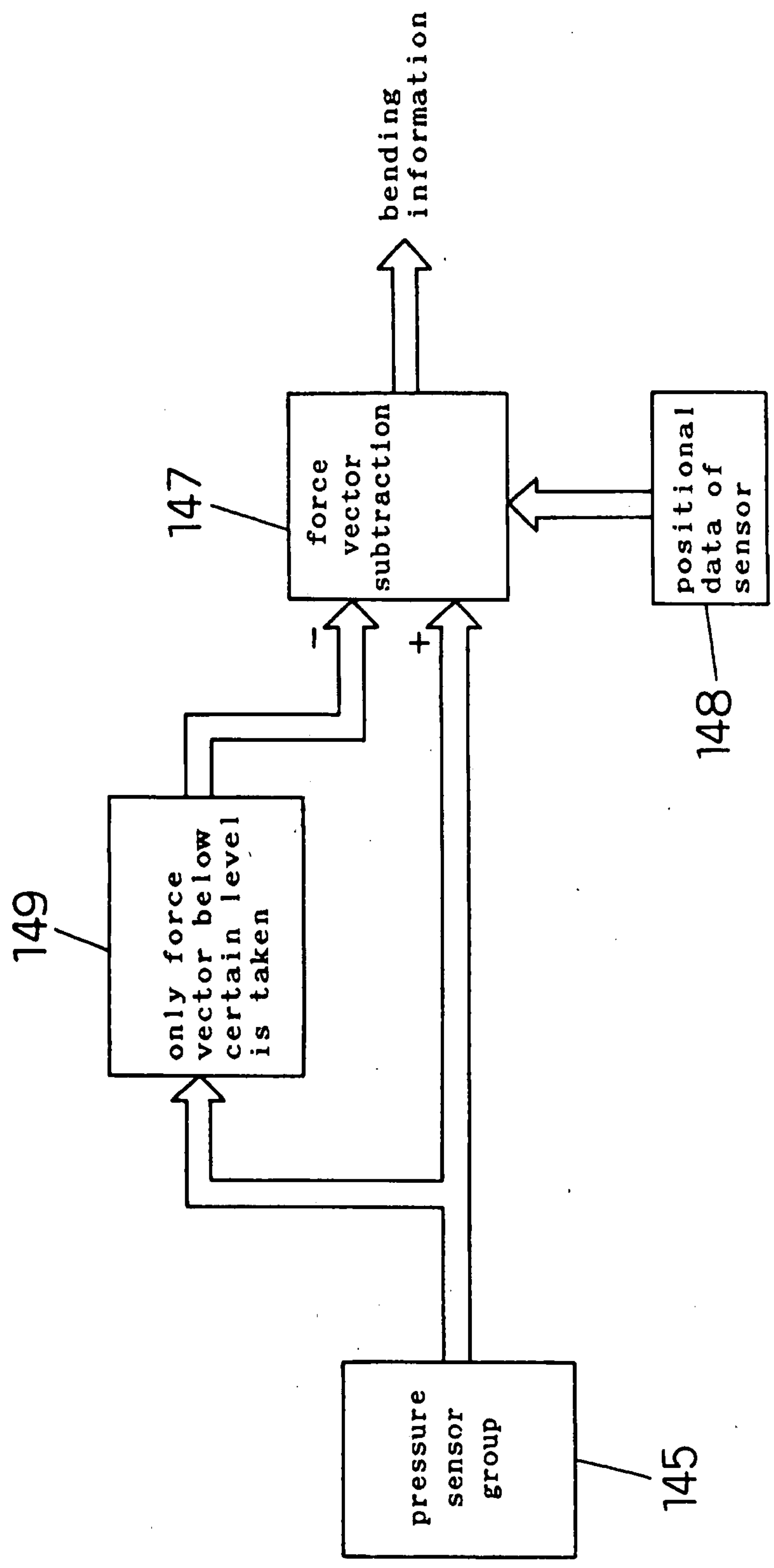

bending information
147
force vector subtraction
148
positional data of sensor
149
only force vector below certain level is taken
-
+
145
pressure sensor group

Fig. 38

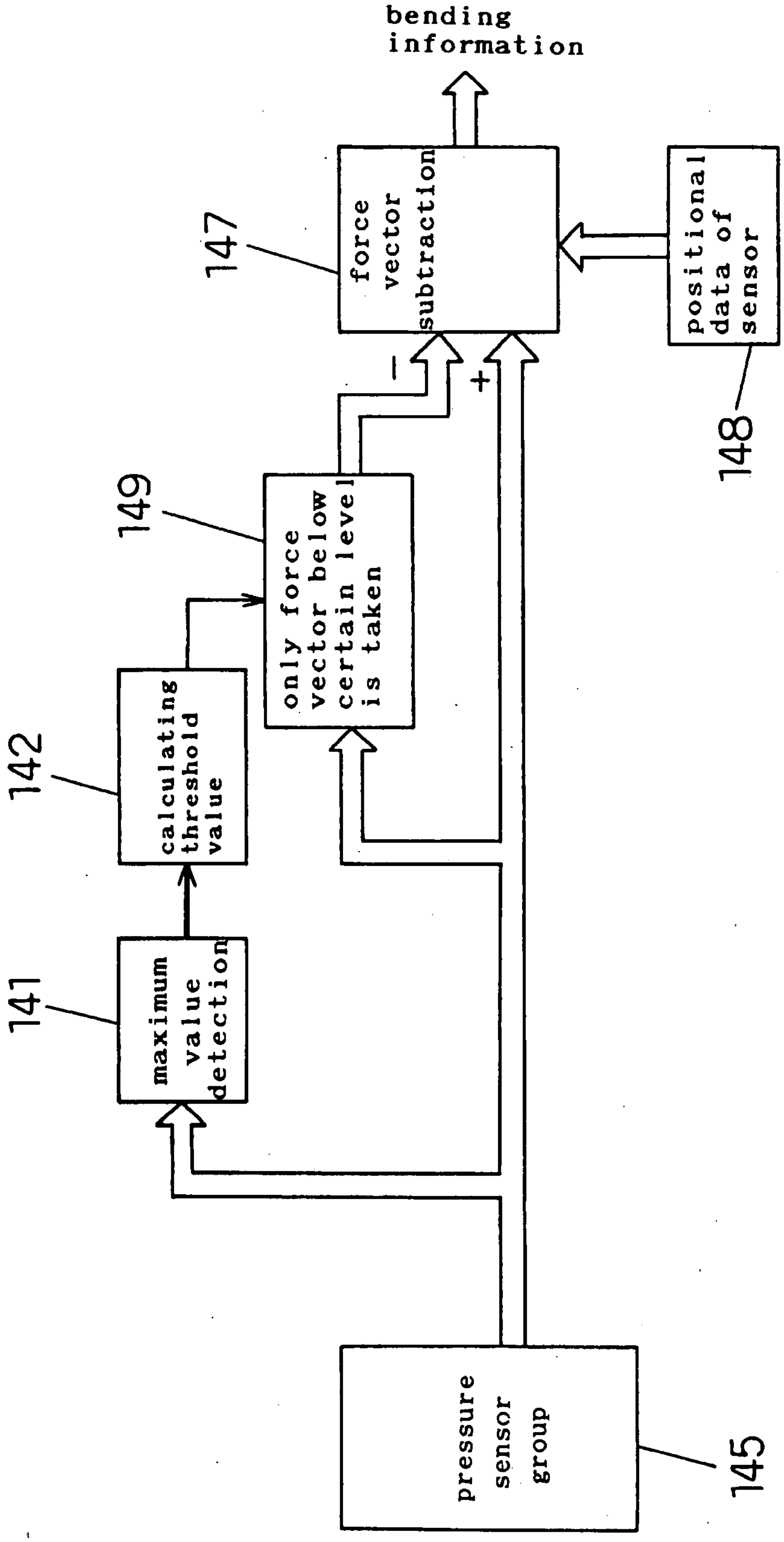

bending information
force vector subtraction
147
positional data of sensor
148
−
+
only force vector below certain level is taken
149
calculating threshold value
142
maximum value detection
141
pressure sensor group
145

Fig. 39

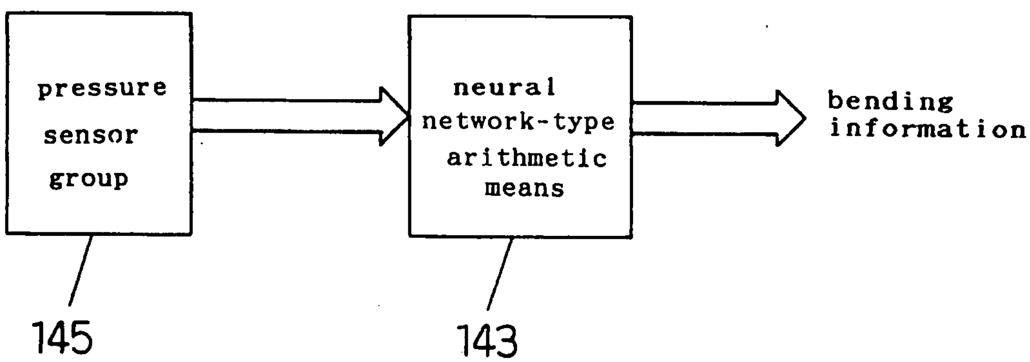

pressure
sensor
group
neural
network-type
arithmetic
means
bending
information
145
143

Fig. 41

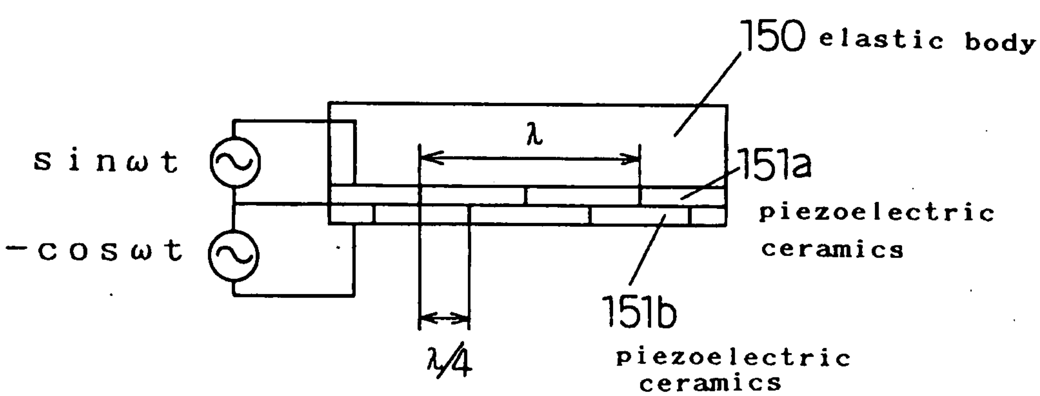
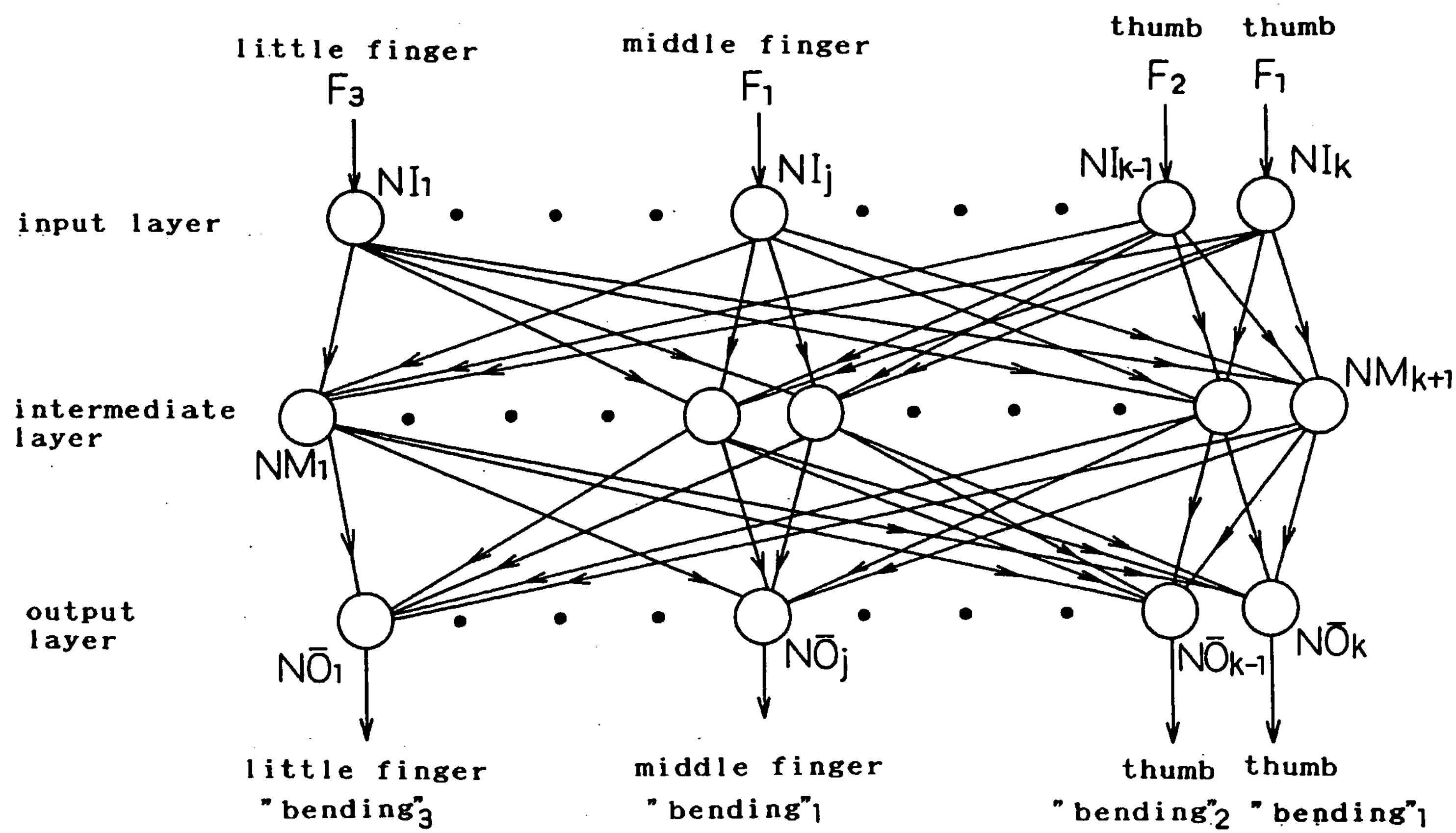

150 elastic body
sinωt
-cosωt
λ
151a
piezoelectric
ceramics
151b
piezoelectric
ceramics
λ/4

Fig. 40



little finger
F_3
middle finger
F_1
thumb
F_2
thumb
F_1
NI_1
NI_j
NI_{k-1}
NI_k
input layer
intermediate layer
NM_1
NM_{k+1}
output layer
$N\bar{O}_1$
$N\bar{O}_j$
$N\bar{O}_{k-1}$
$N\bar{O}_k$
little finger "bending"$_3$
middle finger "bending"$_1$
thumb "bending"$_2$
thumb "bending"$_1$

Fig. 42

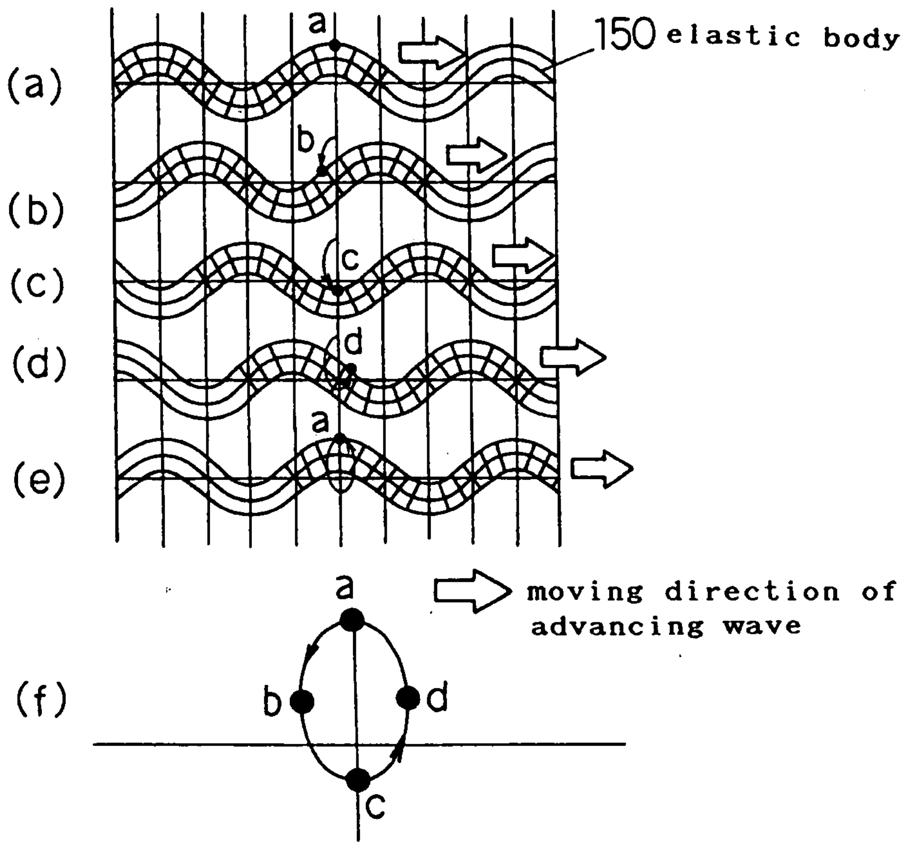
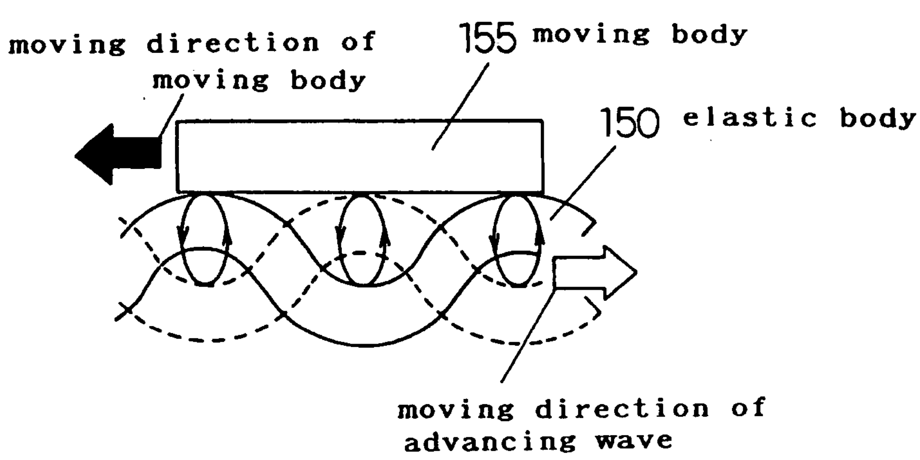
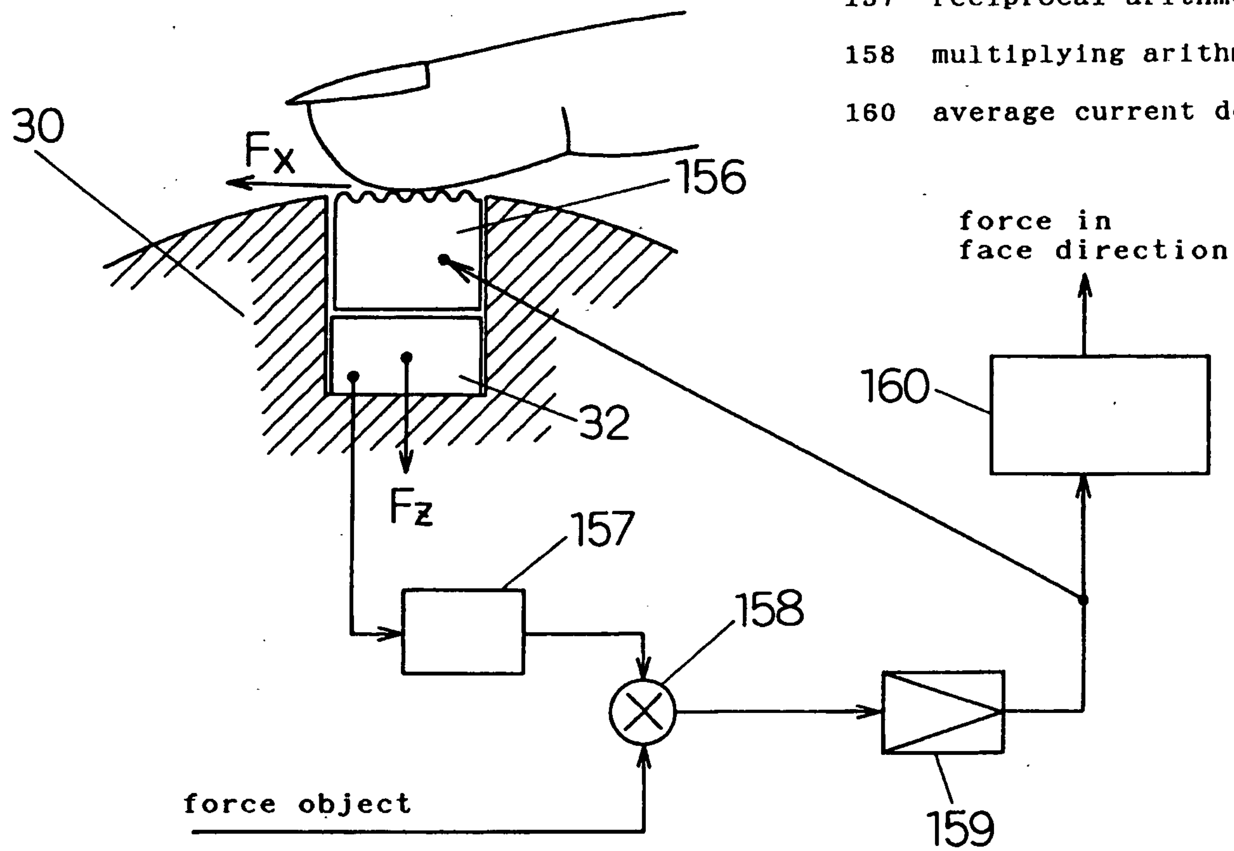

a
150 elastic body
(a)
b
(b)
c
(c)
d
(d)
a
(e)
a
moving direction of
advancing wave
(f)
b
d
c

Fig. 43


moving direction of
moving body
155 moving body
150 elastic body
moving direction of
advancing wave

F i g. 4 4



156 ultrasonic vibration motor

157 reciprocal arithmetic means

158 multiplying arithmetic means

160 average current detecting means

Xerox 4110
Banner Sheet

gbarron

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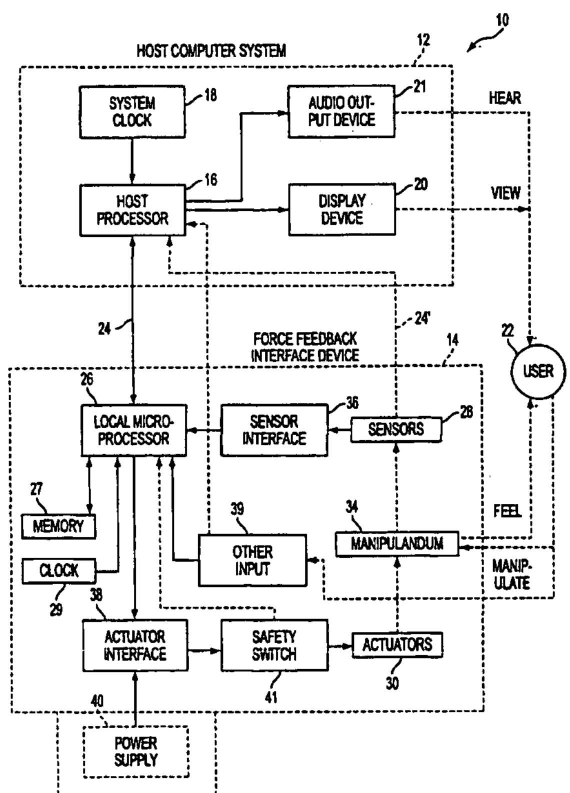
[Continued on next page]

(54) Title: CONTROLLING VIBROTACTILE SENSATIONS FOR HAPTIC FEEDBACK DEVICES



(57) Abstract: Method and apparatus for controlling vibrotactile sensations for haptic feedback devices. An actuator (30) in a haptic feedback device includes a rotatable eccentric mass (104), and information is received at the haptic feedback device causing a drive signal. The drive signal controls the actuator (30) to oscillate the mass in two directions about an axis (A) of rotation of the actuator (30) such that the oscillation of the mass induces a vibration in the haptic feedback device. The magnitude and frequency of the vibration can be independently controlled by adjusting a magnitude and a frequency, respectively, of the drive signal. The vibrations can also be provided in a bi-directional mode or uni-directional mode to provide the most efficient magnitude of the vibrotactile sensations. The haptic feedback device can be, for example, a gamepad controller receiving commands from a host computer providing a graphical environment.

WO 01/03105 A1

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CONTROLLING VIBROTACTILE SENSATIONS FOR HAPTIC FEEDBACK DEVICES

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Application No. 60/142,155, filed July 1, 1999, entitled, "Providing Vibration Forces in Force Feedback Devices," and which is incorporated by reference herein.

BACKGROUND OF THE INVENTION

The present invention relates generally to producing forces in haptic feedback interface devices, and more particularly to the output and control of vibrations and similar force sensations from actuators in a haptic feedback interface device.

Using an interface device, a user can interact with an environment displayed by a computer system to perform functions and tasks on the computer, such as playing a game, experiencing a simulation or virtual reality environment, using a computer aided design system, operating a graphical user interface (GUI), or otherwise influencing events or images depicted on the screen. Common human-computer interface devices used for such interaction include a joystick, mouse, trackball, steering wheel, stylus, tablet, pressure-sensitive ball, or the like, that is connected to the computer system controlling the displayed environment.

In some interface devices, force feedback or tactile feedback is also provided to the user, also known more generally herein as "haptic feedback." These types of interface devices can provide physical sensations which are felt by the user using the controller or manipulating the physical object of the interface device. One or more motors or other actuators are used in the device and are connected to the controlling computer system. The computer system controls forces on the haptic feedback device in conjunction and coordinated with displayed events and interactions on the host by sending control signals or commands to the haptic feedback device and the actuators.

Many low cost haptic feedback devices provide forces to the user by vibrating the manipulandum and/or the housing of the device that is held by the user. The output of simple vibration haptic feedback (tactile sensations) requires less complex hardware components and software control over the force-generating elements than does more sophisticated haptic feedback. For example, in many current game controllers for game consoles such as the Sony

Playstation and the Nintendo 64, one or more motors are mounted in the housing of the controller and which are energized to provide the vibration forces. An eccentric mass is positioned on the shaft of each motor, and the shaft is rotated quickly to cause the motor and the housing of the controller to vibrate. The host computer (console unit) provides commands to the controller to turn the vibration on or off or to increase or decrease the frequency of the vibration by varying the rate of rotation of the motor.

One problem with the current implementations of providing vibration haptic feedback is that the vibrations that these implementations produce are very limited and cannot be significantly varied. For example, the frequency of the vibrations output by the controllers described above can be adjusted by the host computer, but the magnitude of these vibrations cannot be varied independently from the frequency. These devices can only provide vibration magnitudes that are directly proportional to frequency; thus, low-frequency vibrations must have a low magnitude, and high frequency vibrations must have a high magnitude. Developers have no way of providing, for example, vibrations having a high frequency and low magnitude or vibrations having a low frequency and high magnitude, thus severly limiting the force feedback effects which can be experienced by a user of the device.

SUMMARY OF THE INVENTION

The present invention is directed to controlling vibrotactile sensations in haptic feedback devices which are interfaced with a host application program. The present invention allows more varied and complex sensations to be provided using inexpensive electronics and mechanical parts.

More specifically, the present invention relates to a method for providing a vibration for a haptic feedback device. An actuator in a haptic feedback device is provided and includes a rotatable mass, and a drive signal is received at the haptic feedback device. The drive signal controls the actuator to oscillate the mass in two directions about an axis of rotation of the actuator such that the oscillation of the mass induces a vibration in the haptic feedback device. The magnitude and frequency of the vibration can be independently controlled by adjusting a magnitude and a frequency, respectively, of the drive signal.

The mass of the actuator can be an eccentric mass, and the oscillation can be accomplished in a bi-directional mode, where a different drive signal is provided to the actuator in a uni-directional mode to rotate the eccentric mass in a single direction about the axis of rotation of the shaft. The uni-directional mode can be used to output high magnitude, low frequency vibrotactile effects, and the bi-directional mode can be used to output high frequency vibrotactile effects. The haptic feedback device can be a gamepad controller receiving commands from a host computer which determines when the vibration is to be output based on events occurring within a graphical environment implemented and displayed by the computer.

Another aspect of the invention is concerned with a method for commanding a vibration for a haptic feedback device from a host computer that implements a graphical environment. An indication to output information to cause a haptic effect to be output to a user of the haptic feedback device. The indication is caused by an event or interaction occurring in the graphical environment of the host computer. Information is provided to the haptic feedback device and includes a magnitude and a frequency that are independently adjustable. An actuator is caused to oscillate a mass about an axis of rotation in two directions to cause a vibration in the haptic feedback device, where a magnitude and a frequency of the vibration is based on the magnitude and frequency included in the information. The indication to output the information can received by a force feedback driver program running on the host computer, or another software layer. The information provided to the haptic feedback device can be a command including parameters describing the magnitude and frequency, or can be a drive signal which is provided to the actuator.

In another aspect, a haptic feedback device provides vibrotactile sensations to a user, is coupled to a host computer and includes a housing and an actuator coupled to the housing and

including a mass, wherein said mass can be rotated by the actuator. The device also includes a circuit for driving the actuator in two directions, the circuit receiving a drive signal and causing the actuator to oscillate the mass and induce a vibration in the housing. The vibration is experienced by the user as vibrotactile sensations. The mass can be an eccentric mass positioned offset on the rotating shaft. The circuit for driving the actuator can include an H-bridge circuit or can include two linear amplifiers. The haptic feedback device can be a gamepad controller that receives information from the host which determines when the vibrotactile sensations are to be output based on events occurring within a graphical environment implemented and displayed by the host computer.

The present invention advantageously provides a haptic feedback device that can output a wide variety of vibrotactile sensations. Both the frequency and amplitude of the vibrations can be controlled using bi-directional control features, allowing a much wider range of sensations to be experienced by the user than in the uni-directional prior art devices. Furthermore, the device is low in cost to produce and is thus quite suitable for home consumer applications.

These and other advantages of the present invention will become apparent to those skilled in the art upon a reading of the following specification of the invention and a study of the several figures of the drawing.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a block diagram of a control system for the haptic feedback interface device of the present invention;

FIGURE 2a is a perspective view of one embodiment of a motor having an eccentric mass that is rotated to provide vibrations to an interface device;

FIGURES 2b and 2c are top plan views of a motor and differently-shaped eccentric masses;

FIGURE 3 is a graph illustrating a vibration magnitude vs. motor voltage for prior art devices;

FIGURE 4 is a graph illustrating a vibration magnitude vs. frequency of oscillation of the eccentric or drive signal;

FIGURE 5a is a schematic diagram illustrating a first example of a drive circuit which can be used to drive the actuator in bi-directional mode; and

FIGURE 5b is a schematic disgram illustrating a second example of a drive circuit which can be used to drive the actuator in bi-directional mode.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

FIGURE 1 is a block diagram illustrating a force feedback interface system 10 for use with the present invention controlled by a host computer system. Interface system 10 includes a host computer system 12 and an interface device 14.

Host computer system 12 can be any of a variety of computer systems, such as a home video game systems (game console), e.g. systems available from Nintendo, Sega, or Sony. Other types of computers may also be used, such as a personal computer (PC, Macintosh, etc.), a television "set top box" or a "network computer," a workstation, a portable and/or handheld game device or computer, etc. Host computer system 12 preferably implements a host application program with which a user 22 is interacting via peripherals and interface device 14. For example, the host application program can be a video or computer game, medical simulation, scientific analysis program, operating system, graphical user interface, or other application program that utilizes force feedback. Typically, the host application provides images to be displayed on a display output device, as described below, and/or other feedback, such as auditory signals. The host application, or a driver program, API or other layer running on the host computer, preferably sends out information to cause haptic feedback to the user on the device 14, as described below, based on events or interactions occuring within the host application. For example, when a user-controlled vehicle collides with a fence in a game or simulation, a vibration can be output to the user to enhance the interactive experience of the collision. Similarly, when a user-controlled cursor moves onto another object such as an icon or text heading, vibrations can be used to inform the user of the interaction.

Host computer system 12 preferably includes a host microprocessor 16, a clock 18, a display screen 20, and an audio output device 21. Microprocessor 16 can be one or more of any of well-known microprocessors. Random access memory (RAM), read-only memory (ROM), and input/output (I/O) electronics are preferably also included in the host computer. Display screen 20 can be used to display images generated by host computer system 12 or other computer systems, and can be a standard display screen, television, CRT, flat-panel display, 2-D or 3-D display goggles, or any other visual interface. Audio output device 21, such as speakers, is preferably coupled to host microprocessor 16 via amplifiers, filters, and other circuitry well known to those skilled in the art and provides sound output to user 22 from the host computer 12. Other types of peripherals can also be coupled to host processor 16, such as storage devices (hard disk drive, CD ROM/DVD-ROM drive, floppy disk drive, etc.), communication devices, printers, and other input and output devices. Data for implementing the interfaces of the present invention can be stored on computer readable media such as memory (RAM or ROM), a hard disk, a CD-ROM or DVD-ROM, etc.

An interface device 14 is coupled to host computer system 12 by a bi-directional bus 24. Interface device 14 can be a gamepad controller, joystick controller, mouse controller, steering wheel controller, or other device which a user may manipulate to provide input to the computer system and experience force feedback. The bi-directional bus sends signals in either direction between host computer system 12 and the interface device. An interface port of host computer system 12, such as an RS232 or Universal Serial Bus (USB) serial interface port, parallel port, game port, etc., connects bus 24 to host computer system 12. Alternatively, a wireless communication link can be used.

Interface device 14 includes a local microprocessor 26, sensors 28, actuators 30, a user object 34, optional sensor interface 36, an actuator interface 38, and other optional input devices 39. Local microprocessor 26 is coupled to bus 24 and is considered local to interface device 14 and is dedicated to force feedback and sensor I/O of interface device 14. Microprocessor 26 can be provided with software instructions to wait for commands or requests from computer host 12, decode the command or request, and handle/control input and output signals according to the command or request. In addition, processor 26 preferably operates independently of host computer 12 by reading sensor signals and calculating appropriate forces from those sensor signals, time signals, and stored or relayed instructions selected in accordance with a host command. Suitable microprocessors for use as local microprocessor 26 include the MC68HC711E9 by Motorola, the PIC16C74 by Microchip, and the 82930AX by Intel Corp., for example. Microprocessor 26 can include one microprocessor chip, or multiple processors and/or co-processor chips, and/or digital signal processor (DSP) capability.

Microprocessor 26 can receive signals from sensors 28 and provide signals to actuators 30 of the interface device 14 in accordance with instructions provided by host computer 12 over bus 24. For example, in a preferred local control embodiment, host computer 12 provides high level supervisory commands to microprocessor 26 over bus 24, and microprocessor 26 manages low level force control loops to sensors and actuators in accordance with the high level commands and independently of the host computer 12. The force feedback system thus provides a host control loop of information and a local control loop of information in a distributed control system. This operation is described in greater detail in U.S. Patent No. 5,734,373, incorporated herein by reference. Microprocessor 26 can also receive commands from any other input devices 39 included on interface apparatus 14, such as buttons, and provides appropriate signals to host computer 12 to indicate that the input information has been received and any information included in the input information. Local memory 27, such as RAM and/or ROM, can be coupled to microprocessor 26 in interface device 14 to store instructions for microprocessor 26 and store temporary and other data (and/or registers of the microprocessor 26 can store data).. In addition, a local clock 29 can be coupled to the microprocessor 26 to provide timing data.

Sensors 28 sense the position, motion, and/or other characteristics of a user manipulandum 34 of the interface device 14 along one or more degrees of freedom and provide

signals to microprocessor 26 including information representative of those characteristics. Rotary or linear optical encoders, potentiometers, photodiode or photoresistor sensors, velocity sensors, acceleration sensors, strain gauge, or other types of sensors can be used. Sensors 28 provide an electrical signal to an optional sensor interface 36, which can be used to convert sensor signals to signals that can be interpreted by the microprocessor 26 and/or host computer system 12. For example, these sensor signals can be used by the host computer to influence the host application program, e.g. to steer a race car in a game or move a cursor across the screen.

One or more actuators 30 transmit forces to the interface device 14 and/or to manipulandum 34 of the interface device 14 in response to signals received from microprocessor 26. In one embodiment, the actuators output forces on the housing of the interface device 14 which is handheld by the user, so that the forces are transmitted to the manipulandum through the housing. Alternatively or additionally, actuators can be directly coupled to the manipulandum 34. Actuators 30 can include two types: active actuators and passive actuators. Active actuators include linear current control motors, stepper motors, pneumatic/hydraulic active actuators, a torquer (motor with limited angular range), voice coil actuators, moving magnet actuators, and other types of actuators that transmit a force to move an object. Passive actuators can also be used for actuators 30, such as magnetic particle brakes, friction brakes, or pneumatic/hydraulic passive actuators. Active actuators are preferred in the embodiments of the present invention. Actuator interface 38 can be connected between actuators 30 and microprocessor 26 to convert signals from microprocessor 26 into signals appropriate to drive actuators 30, as is decribed in greater detail below.

Other input devices 39 can optionally be included in interface device 14 and send input signals to microprocessor 26 or to host processor 16. Such input devices can include buttons, dials, switches, levers, or other mechanisms. For example, in embodiments where the device 14 is a gamepad, the various buttons and triggers can be other input devices 39. Or, if the user manipulandum 34 is a joystick, other input devices can include one or more buttons provided, for example, on the joystick handle or base. Power supply 40 can optionally be coupled to actuator interface 38 and/or actuators 30 to provide electrical power. A safety switch 41 is optionally included in interface device 14 to provide a mechanism to deactivate actuators 30 for safety reasons.

Manipulandum (or "user object") 34 is a physical object, device or article that may be grasped (held in the hand between two or more fingers or in the palm) or otherwise contacted or controlled by a user and which is coupled to interface device 14. In some embodiments, the user 22 can manipulate and move the manipulandum along provided degrees of freedom to interface with the host application program the user is viewing on display screen 20. Manipulandum 34 in such embodiments can be a joystick, mouse, trackball, stylus (e.g. at the end of a linkage), steering wheel, sphere, medical instrument (laparoscope, catheter, etc.), pool cue (e.g. moving the cue through actuated rollers), hand grip, knob, button, or other object. Mechanisms can be

used to provide degrees of freedom to the manipulandum, such as gimbal mechanisms, slotted yoke mechanisms, flexure mechanisms, etc. Various embodiments of suitable mechanisms are described in Patent Nos. 5,767,839; 5,721,566; 5,623,582; 5,805,140; and 5,825,308, all incorporated herein by reference.

In other embodments, the haptic feedback can be output directly on the housing of a device, such as a handheld device. For example, the housing can be used for a gamepad, remote control, telephone, or other handheld device. In a gamepad embodiment, the housing of the gamepad can receive the vibrotactile feedback of the present invention, and a fingertip joystick or other control on the gamepad can be provided with separate haptic feedback, e.g. with motors coupled to the joystick mechanism to provide force feedback in the degrees of freedom of the joystick, and/or tactile feedback. Some gamepad embodiments may not include a joystick, so that manipulandum 34 can be a button pad or other device for inputting directions or commands to the host computer.

Controlling Force Feedback Vibrations Using Bi-directional Motor Output

The present invention provides more control over vibrotactile feedback using an actuator having a moving mass. In existing implementations, the moving mass is rotated by a rotary actuator, as described below.

FIGURE 2a is a graph illustrating a DC rotary motor 100 that can be included in a handheld controller 14 or coupled to manipulandum 34 as actuator 30 for providing force feedback to the user of the controller 14 and/or manipulandum 34. Motor 100 includes a shaft 102 that rotates about an axis A, and an eccentric mass 104 is rigidly coupled to the shaft 102 and thus rotates with the shaft about axis A. In one preferred embodiment, the housing 106 of the motor 100 is coupled to the housing of the interface device 14, e.g. the motor can be attached to the inside of the housing of a handheld gamepad or other controller. In other embodiments, the actuator can be coupled to a movable manipulandum, such as a joystick or mouse, or other member.

Many different types and shapes of eccentric masses 104 can be used. As shown in FIGURE 2b, a wedge- or pie-shaped eccentric can be used, where one end of the eccentric is coupled to the shaft 102 so that most of the wedge extends to one side of the shaft. Alternatively, as shown in FIGURE 2c, a cylindrical or other-shaped mass 108 can be coupled to the shaft 102. The center 110 of the mass 108 is positioned to be offset from the axis of rotation A of the shaft 102, creating an eccentricity parameter e that is determined by the distance between the axis of rotation of the shaft 102 and the center of mass of the mass 108. The e parameter can be adjusted in different device embodiments to provide stronger or weaker vibrations, as desired. For example, the radial force due to the unbalanced rotating mass is given

by F = m * w^2 * e, where m is the rotating mass, w is the angular velocity, and e is the eccentricity. This relationship predicts that greater magnitude is obtained by changing the eccentricity if the motor is driven constantly in one direction.

When the eccentric mass 104 is rotated by the motor 100, a vibration is induced in the motor and in any member coupled to the motor due to the off-balance motion of the mass. Since the housing 106 of motor 100 is preferably coupled to a housing of a controller or to a movable manipulandum, the vibration is transmitted to the user that is holding the housing or manipulandum. One or more of motors 100 can be included in a device 14 to provide vibrotactile or other haptic feedback; for example, two motors may be used to provide stronger magnitude vibrations and/or vibrations in two different directions.

FIGURE 3 is a graph 112 illustrating a uni-directional mode of the motor 100 used in the prior art for outputting vibrotactile feedback. In this mode, the motor is controlled by a voltage value to rotate the eccentric mass in one direction about the axis of rotation of the shaft. For example, a local microprocessor can output a voltage directly to the motor, or an actuator interface can provide the desired voltage value to the motor 100. Typically, an on-off drive voltage signal is used, where the duty cycle of the drive signal indicates the actual voltage seen across the motor.

The graph 112 shows the relationship between voltage (the horizontal axis) and acceleration on the surface of the housing of the controller device 14 (the vertical axis). A top portion and a side portion of the housing are areas where the acceleration has been measured for this graph, as indicated by the different curves; in addition, a large eccentric mass and a smaller eccentric mass were used. The magnitude of acceleration is indicative of the magnitude of vibration as experienced by the user. As shown, the vibration increases in magnitude proportionally with the magnitude of voltage used to control the motor.

Prior art gamepad controllers, such as the Sony Dual-Shock™ or the Dual Impact by Performance, use the uni-directional mode to provide vibrotactile feedback to a controller held by the user. An advantage of this mode is that strong vibrations can be provided to the user. However, the strength of the vibrations is directly tied to the frequency of the vibration, i.e. the revolutions-per-minute of the eccentric mass about the shaft's axis of rotation, so that the higher the frequency, the higher the vibration magnitude. Thus, a high frequency, low magnitude vibration cannot be output. Similarly, a low frequency, high strength vibration cannot be output for a particular mass and eccentricity.

FIGURE 4 is a graph 120 illustrating the output results of a bi-directional mode of the present invention of the motor 100 for outputting vibrotactile feedback. In this mode, the motor is controlled by a drive waveform that changes between positive and negative signs, thereby changing the direction of rotation of the motor shaft 102 in accordance with the waveform. In the preferred method of operation, the eccentric mass 104 never completes a full rotation, but is

instead controlled to oscillate approximately about a single point in its range of motion (a forced harmonic). The eccentric mass thus travels through only a portion of the full range of motion of the shaft before it changes direction and moves in the opposite direction. This causes a vibration in the motor and in any member or housing coupled to the motor as the mass is quickly moved back and forth. In practice, it has been found that a minimum frequency must be provided for the eccentric mass to oscillate about a single point; below that natural frequency of the eccentric mass, the mass will tend to shift about the rotational range of the actuator as it oscillates. The natural frequency is determined by the spring constant of the inherent cogging effect (reluctance force) of the motor.

The graph 120 shows the relationship for several motors between frequency of oscillation of the eccentric or drive signal (the horizontal axis) and acceleration on the top surface of the housing of the controller device 14 (the vertical axis). As shown in the graph, for most of the motors shown, a higher frequency of oscillation causes a lower magnitude of vibration, while a lower frequency of oscillation causes a higher magnitude of vibration. The dynamic range of control is much greater in bi-directional mode than in uni-directional mode. The results shown in graph 120 were obtained using a current-controlled linear amplifier; however, a voltage-controlled amplifier can also be used, and/or a switching amplifier can be used as shown in Fig. 5a. The drive waveform can be a current waveform or a voltage waveform, depending on the particular amplifier circuit and other circuitry used in a particular implementation.

The drive waveform can be supplied by a local controller or circuitry, such as microprocessor 26, by an actuator interface 38, or the host computer 12 can directly supply the voltage (using an amplifier) or a command to supply a desired voltage. For example, a force feedback driver program, API, or application program (or other software layer) running on the host computer can provide an actuator command having independently-controllable magnitude and frequency parameters, where the command is provided in response to an event or interaction in the graphical environment provided by the host. The local microprocessor or other circuitry can receive the command and parameters and, in response, provide a drive signal of the appropriate frequency or magnitude to the actuator(s). Alternatively, a host computer program can provide a drive signal directly to the device and actuator(s).

The curves shown in graph 120 are at a maximum amplitude of drive waveform for the motor (i.e. the maximum current which was used to drive the motors in the test resulting in graph 120). If a lower amplitude drive waveform is used, then the magnitude of vibration output is correspondingly lower. This allows the controller of the drive waveform to adjust the magnitude of vibration to a desired level within the allowed magnitude range by adjusting the current magnitude of the waveform. The controller can also adjust the frequency of the drive waveform independently of the amplitude of the drive waveform to adjust the frequency of vibration. This allows different frequency vibrations to be output independently of the

magnitude of those vibrations, thereby providing a degree of control over the vibration that is not possible in uni-directional mode.

Although the maximum magnitude of vibration (acceleration) in bi-directional mode is less than the maximum vibration magnitude that can be output in uni-dirctional mode, the advantage of independently controllable magnitude and frequency of vibration allows a great many haptic feedback effects to be generated that are not possible in uni-directional mode. In uni-directional mode, a vibration can be made strong by increasing the voltage and thus the frequency of rotation of the eccentric mass. However, the strength of vibration must always be associated with a corresponding frequency, causing a similar feel to the user each time a particular-strength of vibration is output. In bi-directional mode, a two vibrations may be of similar magnitude but completely different frequencies, or, have the same frequencies but different magnitudes. This creates a large variety of vibration sensations which can be output to the user.

In one optimized embodiment, both uni-directional mode and bi-directional mode are used in a single hybrid controller device 14. A motor 100 that is configured to operate in bi-directional mode may be able to operate in uni-directional mode, e.g. a voltage controlled bridge circuit may be able to drive the motor in both modes (a current-controlled motor is not as appropriate for uni-directional mode). In some embodiments, an amplifier that can operate as a voltage control amplifier for uni-directional mode and as a different amplifier (e.g. current controlled) for bi-directional mode can be used; or, two different amplifiers can be used which can be alternatively selected, where the appropriate amplifier is selected based on the current mode. Since uni-directional mode can offer vibrations of higher magnitude, this mode can be useful to generate very strong lower-frequency force feedback effects, e.g. explosions, collisions, etc. in a game displayed and implemented by the host computer. For example, a given actuator can be driven with voltage control in uni-directional mode to get large magnitude vibrations from 5 to 80 Hz. The controller (e.g. microprocessor 26) can then switch to bi-directional current control mode to produce high frequency vibrations. This multi-mode approach provides higher bandwidth that would not be possible in uni-directional mode and opens up a whole range of haptic feedback effects. Using this paradigm, for example, a 10 g 5 Hz vibration can be output in uni-directional mode followed by a high frequency decaying ringing to simulate loss of vehicle control followed by impact with a metal guardrail in a racing game implemented by the host computer. Other combinations of uni-directional vibrations and bi-directional vibrations can be provided. In other embodiments, one actuator in the device 14 operates in uni-directional mode, and another actuator can operate in bi-directional mode, allowing a uni-directional vibrations to be output at different times or simultaneously.

The vibration effects described above can be greatly varied by changing the drive waveform. Software tools such as Immersion Studio™ from Immersion Corporation can be

used to design and provide different vibration waveforms and to determine which output is best for a particular application.

FIGURE 5a is a schematic diagram of a first example of a drive circuit 50 which can be used to drive actuator 30 (e.g., motor 100 or other type of actuator). This circuit allows the actuator to operate in bi-directional mode. The circuit can be included in the actuator interface 38 of Fig. 1, for example, or within microprocessor 26 or other circuitry.

Circuit 50 is a well-known H-bridge circuit that allows an input current or voltage to drive the actuator 30 in either direction by providing current or voltage in either direction through the actuator load. Transistors 52, 54, 56, and 58 are provided in the configuration shown and are used as switches to provide voltage or current in one of two directions through the motor 30 depending on the switched configuration. For example, transistors 52 and 54 can be switched on and transistors 56 and 58 can be switched off to provide current in one direction through the motor 30, and transistors 56 and 58 can be switched on while transistors 52 and 54 are switched off to provide current in the other direction through the motor 30. The operation of switching H-bridge circuits are well known to those skilled in the art. Either a voltage-controlled amplifier or a current-controlled amplifier circuit can be used. Other H-bridge switching circuits that use FET transistors can also be used in the present invention.

FIGURE 5b is a diagram of a second example of a drive circuit 60 that can be used to drive actuator 30 in bi-directional mode. Circuit 60 allows an input current to drive the actuator 30 in either direction by providing current in either direction through the actuator load. An input signal is provided at node 62, and is amplified either by linear amplifier 64 or linear amplifier 66 depending on the direction of the current, where an inverter 68 inverts the signal for amplifier 66. Such functionality can be obtained with many commonly available linear amplifier integrated circuits. Any amplifier circuit which is capable of reversing drive current can be used to drive the motor in two directions.

In other embodiments of the present invention, yet other types of actuators can be used. For example, a solenoid having linear motion can be used to provide the bi-directional vibrations described above. Rotary or linear voice coil or moving magnet actuators can also be used.

While this invention has been described in terms of several preferred embodiments, it is contemplated that alterations, permutations and equivalents thereof will become apparent to those skilled in the art upon a reading of the specification and study of the drawings. Furthermore, certain terminology has been used for the purposes of descriptive clarity, and not to limit the present invention. It is therefore intended that the following appended claims include alterations, permutations, and equivalents as fall within the true spirit and scope of the present invention.

What is claimed is:

CLAIMS

1. A method for providing a vibration for a haptic feedback device, the method comprising:

providing an actuator for said haptic feedback device, said actuator including a rotatable mass; and

receiving information at said haptic feedback device, said information causing a drive signal to be produced, said drive signal controlling said actuator to oscillate said mass in two directions about an axis of rotation of said actuator such that said oscillation of said mass induces a vibration in said haptic feedback device, wherein a magnitude and a frequency of said vibration can be independently controlled by adjusting a magnitude and a frequency, respectively, of said drive signal.

2. A method as recited in claim 1 wherein said mass of said actuator is an eccentric mass.

3. A method as recited in claim 2 wherein said oscillation of said eccentric mass in said two directions is accomplished in a bi-directional mode, and wherein a different drive signal is provided to said actuator in a uni-directional mode to rotate said eccentric mass in a single direction about said axis of rotation of said shaft.

4. A method as recited in claim 3 wherein said uni-directional mode is used to output high magnitude, low frequency vibrotactile effects, and wherein said bi-directional mode is used to output high frequency vibrotactile effects.

5. A method as recited in claim 1 wherein said haptic feedback device is a gamepad controller, said gamepad controller communicating with a computer and receiving commands from said computer which determine when said vibration is to be output based on events occurring within a graphical environment implemented and displayed by said computer.

6. A method as recited in claim 5 wherein said gamepad controller includes a joystick having two degrees of freedom and providing input to said host computer when manipulated by said user.

7. A method as recited in claim 1 wherein said drive signal is provided to said actuator using a H-bridge circuit.

8. A method as recited in claim 1 wherein said drive signal is derived from a command from a host computer coupled to said force feedback device and displaying a graphical environment manipulable by a user of said haptic feedback device.

9. A method as recited in claim 2 wherein said eccentric mass is wedge-shaped.

10. A method for commanding a vibration for a haptic feedback device from a host computer, said host computer implementing a graphical environment, the method comprising:

receiving an indication to output information to cause a haptic effect to be output to a user of a haptic feedback device coupled to said host computer, said indication caused by an event or interaction occurring in said graphical environment; and

providing information to said haptic feedback device, said information including a magnitude and a frequency that are independently adjustable, wherein an actuator is caused to oscillate a mass in two directions to cause a vibration in a housing of said haptic feedback device, wherein a magnitude and a frequency of said vibration is based on said magnitude and frequency included in said information.

11. A method as recited in claim 10 wherein said indication to output said information is received by a force feedback driver program running on said host computer.

12. A method as recited in claim 10 wherein said actuator is a rotary actuator and said mass of said actuator is an eccentric mass and is rotated about an axis of rotation of said actuator.

13. A method as recited in claim 12 wherein said oscillation of said mass in said two directions is accomplished in a bi-directional mode, and wherein different information is provided to said actuator in a uni-directional mode to rotate said mass in a single direction about said axis of rotation of said actuator.

14. A method as recited in claim 14 wherein said uni-directional mode is used to output high magnitude, low frequency vibrotactile effects, and wherein said bi-directional mode is used to output high frequency vibrotactile effects.

15. A method as recited in claim 10 wherein said haptic feedback device is a gamepad controller grasped by a hand of a user, and wherein said events occurring within said graphical environment include an interaction of a user-controlled graphical object with a different graphical object.

16. A method as recited in claim 10 wherein said information provided to said haptic feedback device is a command including parameters describing said magnitude and frequency.

17. A method as recited in claim 10 wherein said information provided to said haptic feedback device is a drive signal which is provided to said actuator.

18. A haptic feedback device for providing vibrotactile sensations to a user, said haptic feedback device coupled to a host computer and comprising:

a housing grasped by said user;

an actuator coupled to said housing and including a mass, wherein said mass can be rotated by said actuator; and

a circuit for driving said actuator in two directions, said circuit receiving a drive signal and causing said actuator to oscillate said mass about an axis of rotation and induce a vibration in said housing, said vibration experienced by said user as vibrotactile sensations.

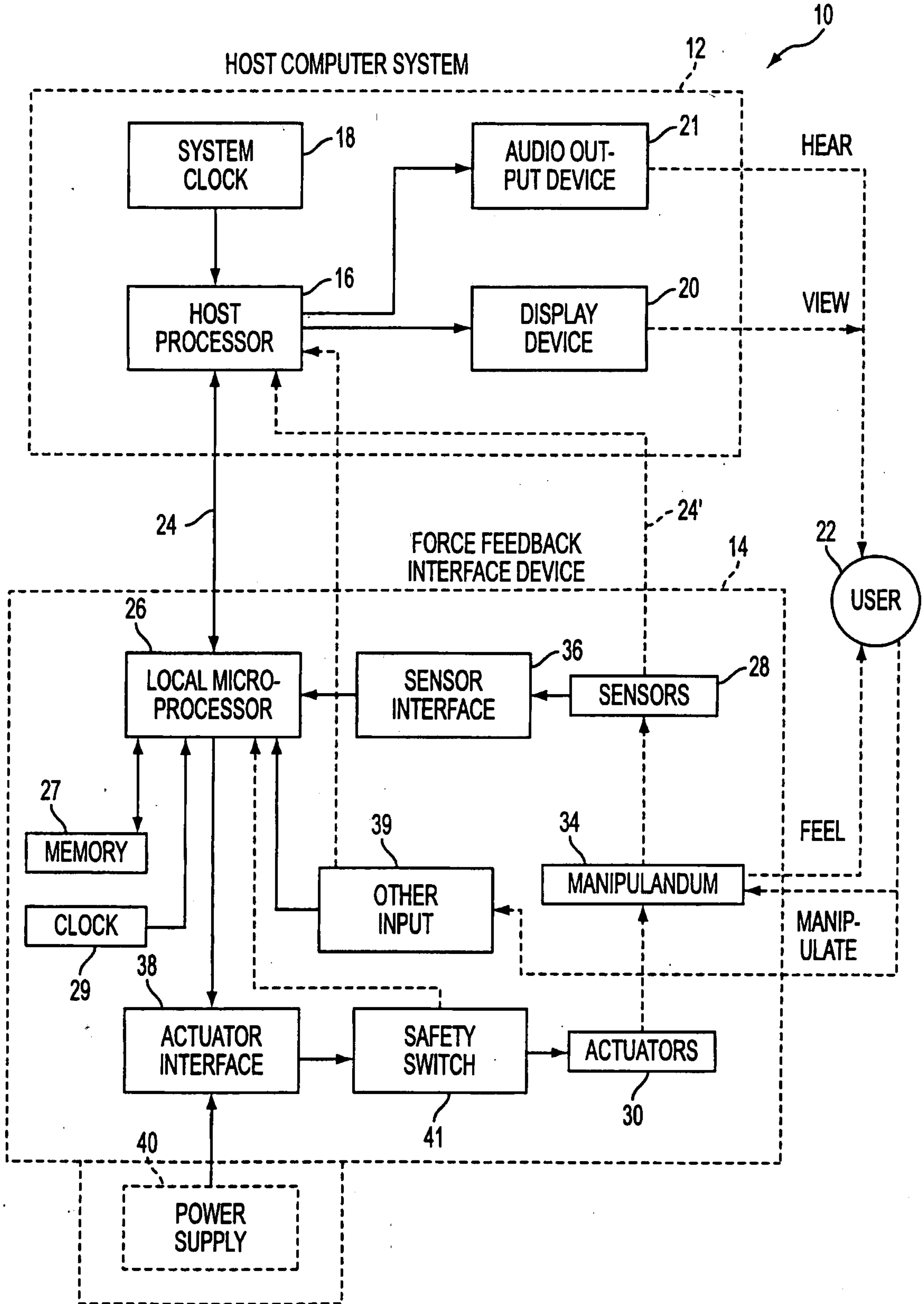
19. A haptic feedback device as recited in claim 18 wherein said mass is an eccentric mass positioned offset on said rotating shaft.

20. A haptic feedback device as recited in claim 18 wherein said circuit for driving said actuator includes an H-bridge circuit that can provide current in two directions through said actuator.

21. A haptic feedback device as recited in claim 18 wherein said circuit for driving said actuator includes two linear amplfiers, each of said linear amplifiers amplifying a signal through said actuator in a different direction to allow said actuator to driven in said two directions.

22. A haptic feedback device as recited in claim 18 wherein said haptic feedback device is a gamepad controller, said gamepad controller receiving information from said host computer which determines when said vibrotactile sensations are to be output based on events occurring within a graphical environment implemented and displayed by said host computer.

23. A method as recited in claim 22 wherein said gamepad controller includes a joystick having two degrees of freedom and providing input to said host computer when manipulated by said user.



10
12
HOST COMPUTER SYSTEM
SYSTEM CLOCK
18
AUDIO OUT-PUT DEVICE
21
HEAR
HOST PROCESSOR
16
DISPLAY DEVICE
20
VIEW
24
24'
FORCE FEEDBACK INTERFACE DEVICE
14
22
USER
26
LOCAL MICRO-PROCESSOR
SENSOR INTERFACE
36
SENSORS
28
27
MEMORY
39
OTHER INPUT
34
MANIPULANDUM
FEEL
MANIP-ULATE
CLOCK
29
38
ACTUATOR INTERFACE
SAFETY SWITCH
ACTUATORS
30
41
40
POWER SUPPLY

FIG. 1

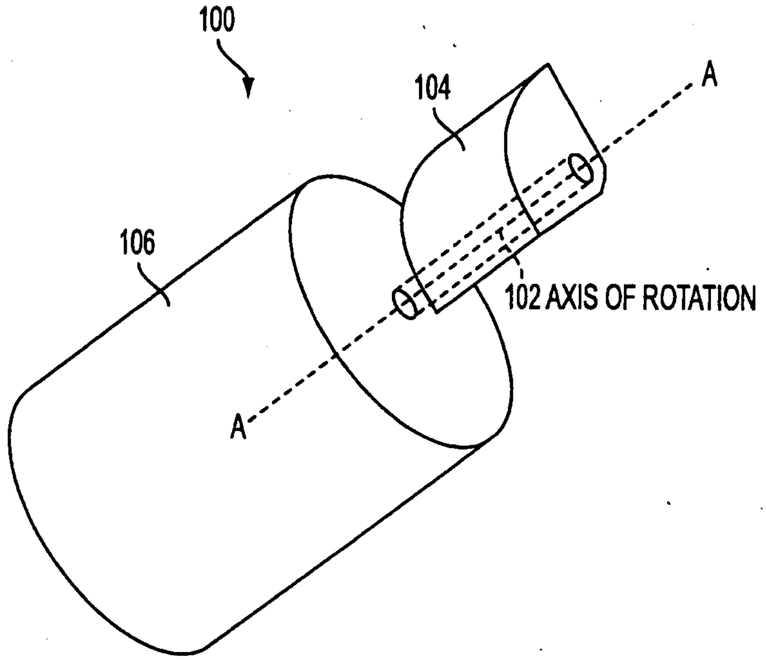


FIG. 2A

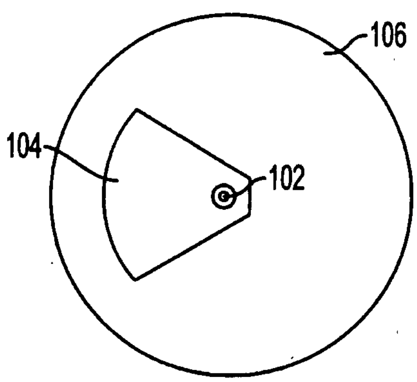


FIG. 2B

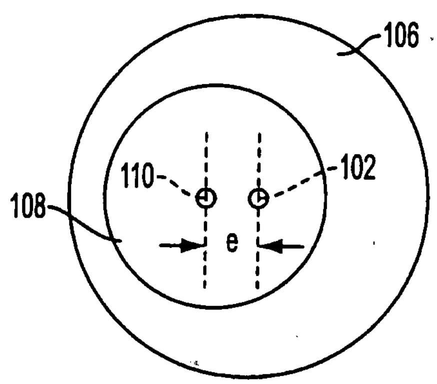


FIG. 2C

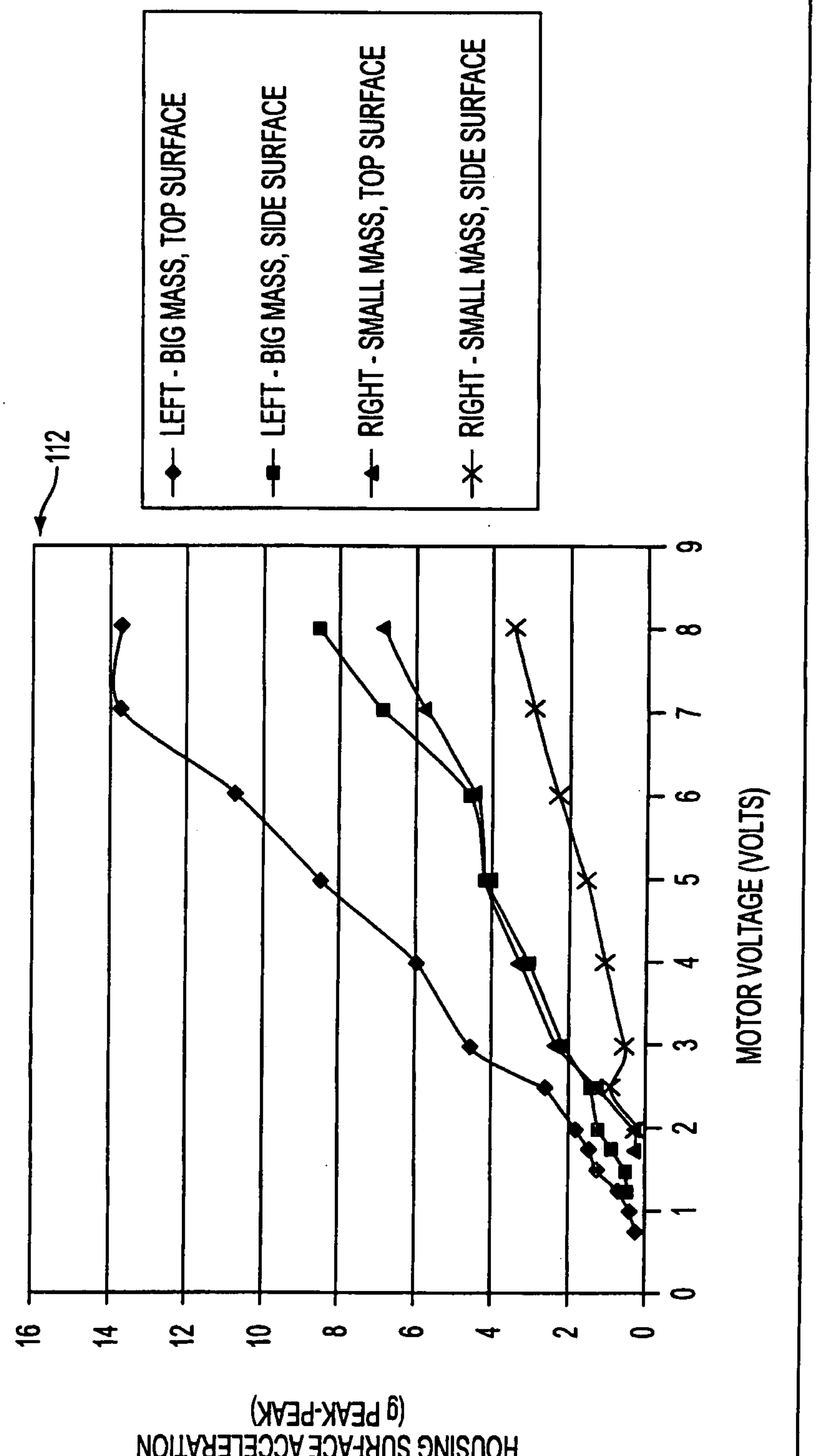

112
LEFT - BIG MASS, TOP SURFACE
LEFT - BIG MASS, SIDE SURFACE
RIGHT - SMALL MASS, TOP SURFACE
RIGHT - SMALL MASS, SIDE SURFACE
HOUSING SURFACE ACCELERATION
(g PEAK-PEAK)
0
2
4
6
8
10
12
14
16
0
1
2
3
4
5
6
7
8
9
MOTOR VOLTAGE (VOLTS)

FIG. 3

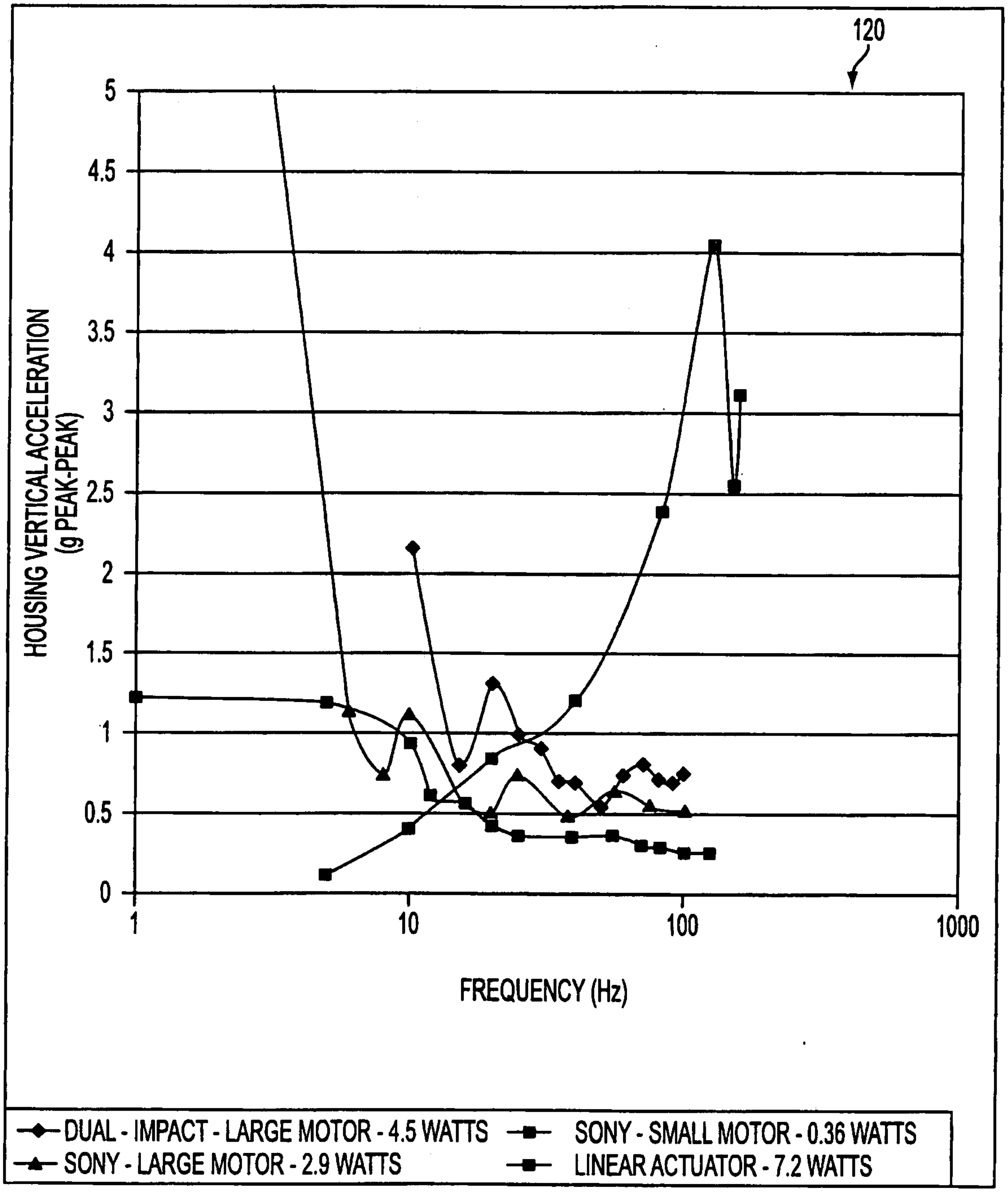

120
HOUSING VERTICAL ACCELERATION (g PEAK-PEAK)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
10
100
1000
FREQUENCY (Hz)
DUAL - IMPACT - LARGE MOTOR - 4.5 WATTS
SONY - LARGE MOTOR - 2.9 WATTS
SONY - SMALL MOTOR - 0.36 WATTS
LINEAR ACTUATOR - 7.2 WATTS

FIG. 4

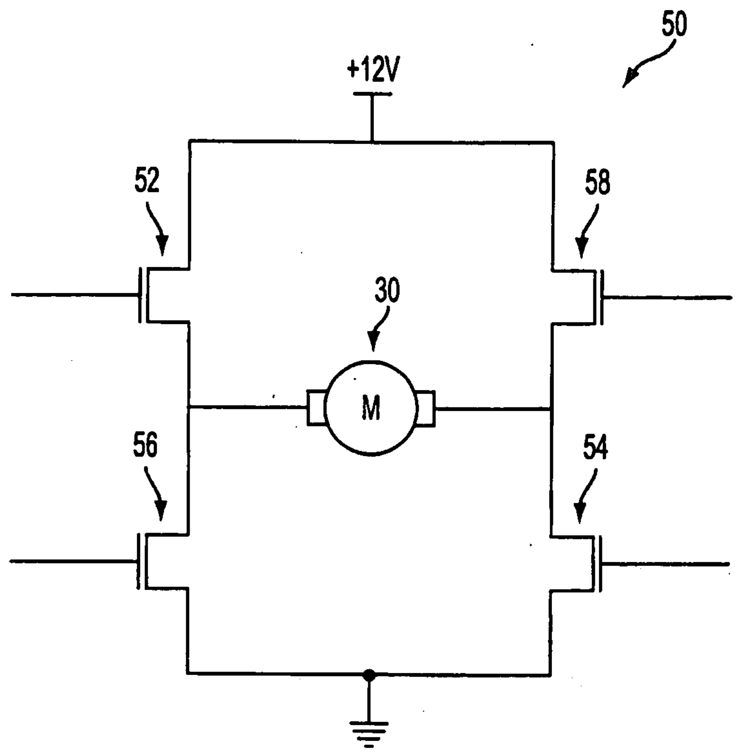


FIG. 5A

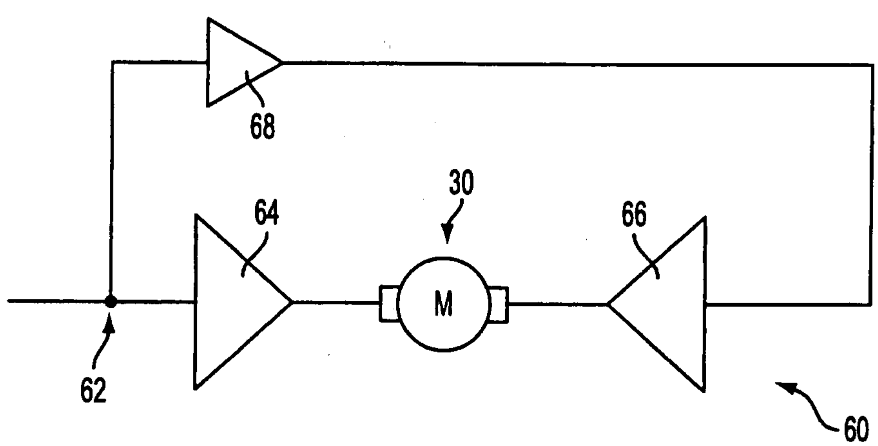


FIG. 5B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/17980

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :G09G 5/00,5/08; H04B 3/36
US CL :345/156,161,163,173,184; 340/407
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 345/156,161,163,173,184; 340/407

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,731,603 A (MCRAE et al.) 15 March 1988, col. 2, lines 6-15, col. 8, line 64-col 9, line 38, col. 9, line 57-64.	1, 2, 5, 8, 9,10-12, 15-19, 22, 23
Y	US 5,296,871 A (PALEY) 22 March 1994, col. 3, lines 40-68, col 4, lines 1-18, col. 5, lines 19-39.	1, 2, 5, 8, 9, 10-12, 15-19, 22, 23

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
26 AUGUST 2000	03 OCT 2000

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